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Caddock

[11] **3,921,119**

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[54] **FILM-TYPE CYLINDRICAL RESISTOR**

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 456,474, April 1, 1974, Pat. No. 3,881,162.

[52] **U.S. Cl.** **338/217;** 338/61; 338/309

[51] **Int. Cl.^{2}** **H01C 3/08**

[58] **Field of Search** 338/61, 308, 309, 328, 338/195, 217

[56] **References Cited**

UNITED STATES PATENTS

3,336,465 8/1967 Hurko 338/308

OTHER PUBLICATIONS

Caddock, 1973 General Catalog, 1973, p. 8.

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[57] **ABSTRACT**

A cylindrical film-type resistor comprising a cylindrical ceramic substrate to which is adherently applied a film of resistive material. Laminated over or under such resistive film are a plurality of termination films of conductive material. The termination films extend longitudinally of the substrate, and are so shaped and connected that the heat generated in the resistive film causes the temperature of the resistor to be substantially uniform throughout the length of the substrate. Stated more specifically, the termination films are combs with intermeshing teeth, and each tooth is relatively narrow at the central region of the substrate and relatively wide at the end portions thereof. Preferably, each comb tooth is generally hourglass-shaped.

22 Claims, 4 Drawing Figures

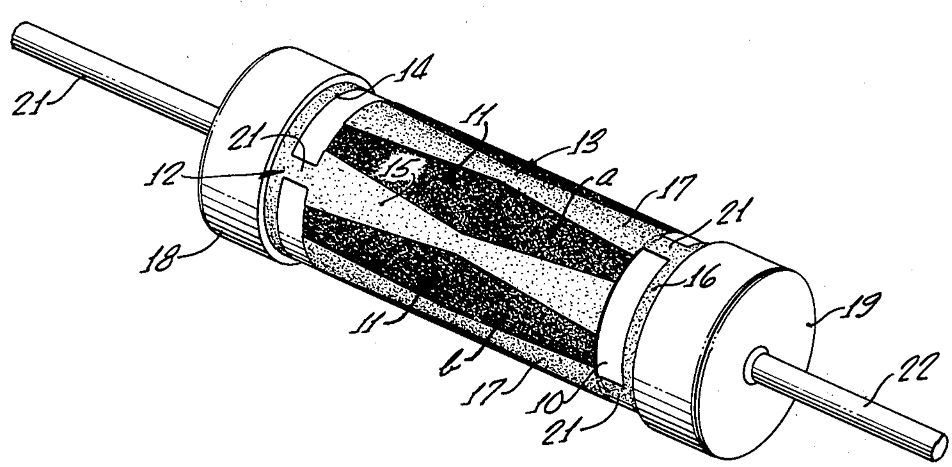


FIG. 1.

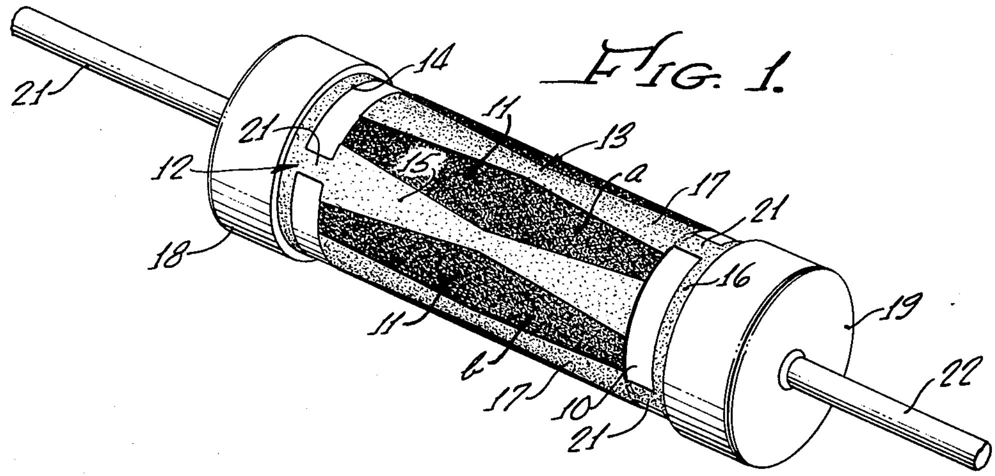


FIG. 2.

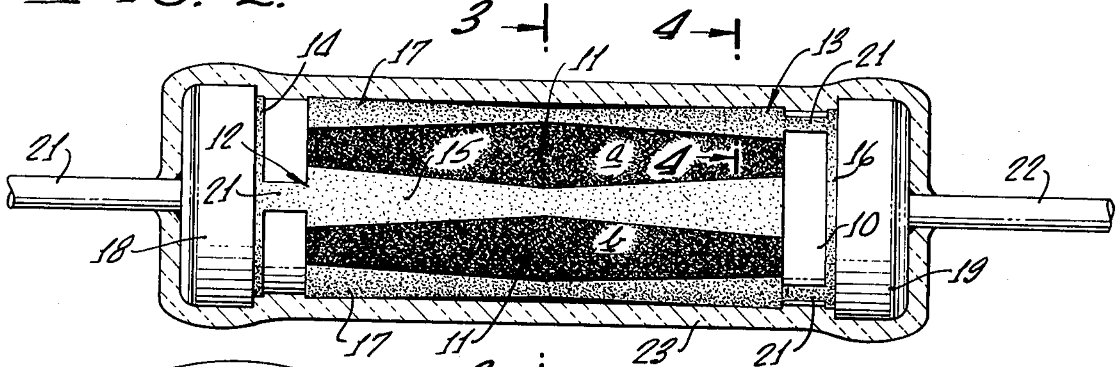
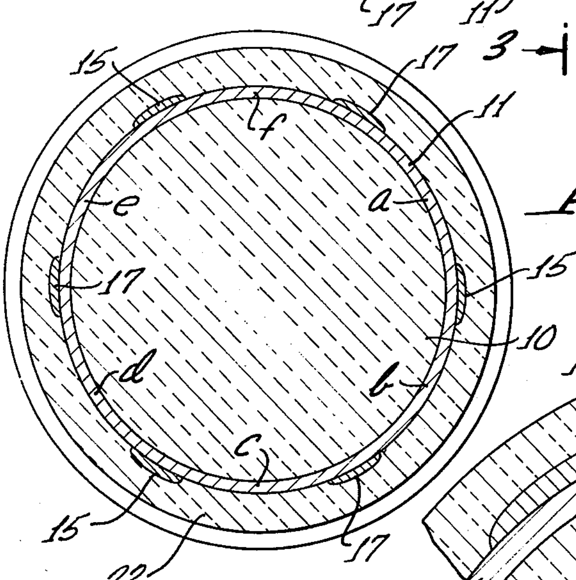


FIG. 3.



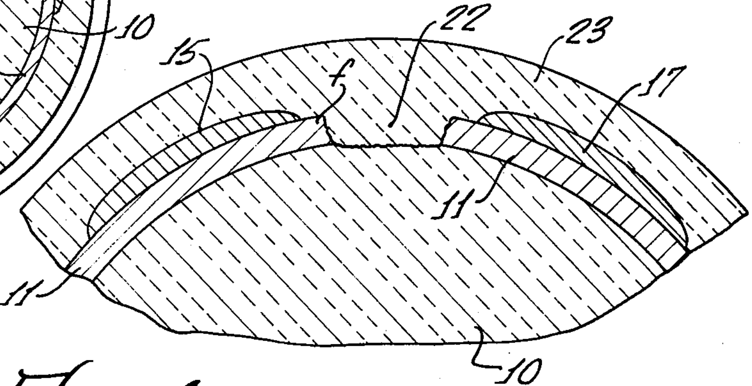


FIG. 4.

FILM-TYPE CYLINDRICAL RESISTOR

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of my co-pending patent application Ser. No. 456,474, filed Apr. 1, 1974, U.S. Pat. No. 3,881,162 issued Apr. 29, 1975, for a Film-Type Cylindrical Resistor and Method of Manufacturing the Same. Said patent application is hereby incorporated by reference herein as though set forth in full.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the field of cylindrical resistors formed of substrates having resistive coatings on the exterior cylindrical surfaces thereof.

2. Description of Prior Art

It is well known that flat ceramic substrates for resistive films are impractical and/or undesirable in numerous applications. For example, where the flat substrate is thin, it has poor resistance to thermal and physical shocks. Thermal shock is an especially major consideration, since the resistor may be very rapidly heated from room temperature to several hundred degrees Fahrenheit. Where the substrate is thick, it tends to have a relatively irregular surface which is difficult to coat with the desired pattern of resistive material.

Cylindrical ceramic substrates, on the other hand, have high shock resistance, particularly when they are solid instead of hollow, and are not scored except in a certain way mentioned below. They also have very smooth and regular surfaces, which are economically formed by centerless grinding. Therefore, it is very often highly desirable and important that the substrates by cylindrical instead of flat.

It is also very desirable, in many applications, that a resistive film having a high inherent resistance (for example, in excess of 50 ohms per square) be so employed that the resistive value of the resistor can be made very low. Low-value film-type resistors have long been known wherein the film is associated with intermeshing comb (or fork, or finger) termination means, whereby parallel connections are made to thus attain low resistance values. However, insofar as applicant is aware, such intermeshing comb termination means do not have the important uniform temperature characteristics referred to in the next paragraph.

The expression "uniform temperature characteristics" refers to a relationship whereby the cylindrical resistor has a substantially uniform temperature along the full length thereof. The end portions of the cylinder are subject to a much greater amount of cooling than is the central region, due to such factors as greater surface area, heat conduction through the end caps and leads, etc. Therefore, unless the ends of the resistor are supplied with amounts of power greater than that supplied to the center, the ends will be at temperature lower than at the center. This is undesirable and inefficient, since the temperature difference necessarily means either that the center is being overheated or that the ends are being underheated. The only way to obtain maximized efficiency and/or stability is to cause the full length of the cylinder to be at substantially the same temperature, that is to say have uniform temperature characteristics, there then being no "hot spots" or excessively cool regions.

There exist various prior-art references which teach cylindrical resistors having uniform-temperature characteristics, but these are not of the intermeshing-comb low-resistance type, and are difficult and expensive to manufacture, are not non-inductive, or have other disadvantages. Usually, such resistors are helical, with the helix groove being cut as by means of a grinding wheel. The spacing between adjacent turns of the helix groove is varied to thus change the width of the resistive helix, with consequent variation in power delivered to different regions of the cylinder. One major disadvantage of the helix is that it usually generates high inductance, and another is that it is impractical or impossible to manufacture satisfactorily by silk-screening. Very importantly, the helical configuration is not practical for low-resistance resistors.

One reference, French Pat. No. 921,934, also teaches two other ways (in addition to grinding a helix groove as stated in the preceding paragraph) to manufacture cylindrical resistors purporting to have uniform-temperature characteristics. One such way comprises providing a layer of good conductive material at the center of the resistor. With such an arrangement, there is a sudden shift from conductive material to resistive material at the resistor center, with consequent absence of smooth, progressive resistance variation along the length of the resistor. The second such way taught by the French patent comprises varying the thickness of the resistive film. This way, however, is characterized by great difficulty and expense of manufacture. For example, it is believed that a film of varying thickness cannot practically and economically be applied by silk-screening.

There also exist prior-art teachings of flat resistors having relatively uniform temperature characteristics, one being FIG. 7 of U.S. Pat. No. 2,838,639. Flat resistors are, however, undesirable for the reasons set forth above and, in the case of FIG. 7 of such U.S. Pat. No. 2,838,639, do not teach the relationships which minimize inductance. Such FIG. 7 does not show an intermeshing-comb resistor, which can have a very low resistance.

Another U.S. Pat., No. 3,336,465, relates to flat resistive elements in an electric stove oven, reference being made to FIG. 3 which shows tapered shapes of film heater portions.

There is, therefore, a major need for a cylindrical resistor which (a) has uniform temperature characteristics, (b) can be manufactured quickly and economically — as by silk-screen application of a uniform-thickness resistive film, (c) is substantially non-inductive, and (d) can have a very low resistance value despite use of high-resistance films.

SUMMARY OF THE INVENTION

The above-stated (and other) needs are met by employing an elongated cylindrical ceramic substrate on which is applied a film of resistive material. Intermeshing comb termination films are applied over the resistive film, with the teeth of the combs extending generally parallel to the substrate axis. End caps are provided at each end of the substrate, in contact with the termination films, and an environmentally protective coating is applied over the entire assembly. The resistive value is accurately trimmed by means of a longitudinal groove as taught by said patent application Ser. No. 456,474. Much less desirably, the termination films are applied under the resistive film, and trimming is achieved by abrading or lapping the resistive film.

Very importantly, the teeth of the combs are so shaped and located that the temperature of the substrate is substantially uniform along the full length thereof. Stated specifically, each comb tooth is caused to be relatively wide near the substrate end portions, and relatively narrow near its center. The spacing between adjacent teeth is thus much greater near the substrate center than near the substrate end portions, the result being that the density of the circumferentially-flowing current is relatively small near the substrate center. The heating effect created by the current is thus less near the center, and this (when the teeth are properly shaped and spaced) causes the temperature of the substrate to be substantially the same along the length thereof.

BRIEF DESCRIPTION OF THE DRAWINGS:

FIG. **1** is an isometric view illustrating a cylindrical film-type resistor constructed in accordance with the present invention, the environmentally-protective coating being unshown;

FIG. **2** is a side elevational view of the resistor, but showing in cross-sectional form the environmentally protective coating in which the entire resistor is encapsulated;

FIG. **3** is an enlarged cross-sectional view taken on line 3—3 of FIG. **2**; and

FIG. **4** is a greatly enlarged fragmentary sectional view taken on line **4—4** of FIG. **2.**

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings, the present resistor comprises an elongated cylinder **10** (the substrate) formed of heat-resistant electrically insulating material, namely a suitable heat-resistant ceramic such as aluminum oxide. To increase the strength thereof, and to minimize the possibility of moisture intrusion, cylinder **10** is preferably solid as distinguished from hollow. It has a smooth exterior surface which is preferbly formed by centerless grinding a ceramic extrusion.

Provided exteriorly on cylinder **10,** in adherent relationship relative to the exterior cylindrical surface thereof, is a resistive film **11.** The film **11** is a continuous cylinder (tube), the ends of which terminate at regions inset substantially distant from the ends of substrate **10.** The thickness of film **11** is substantially uniform (constant).

The resistive material forming film **11** preferably comprises electrically-conductive complex metal oxides in a glass matrix. Another resistive material which may be employed is carbon particles, in an epoxy vehicle which also acts as an adhesive or binder.

First and second termination films **12** and **13** are adherently provided on the substrate, in partially overlying relationship relative to resistive film **11.** Each film **12** and **13** may be referred to as a "comb." Thus, the first termination film **12** has a cylindrical "spine" portion **14** provided in adherent relationship on one end of substrate **10** and spaced away from the corresponding end of resistive film **11.** Integrally connected to spine portion **14** are a plurality of "teeth" **15,** such teeth extending longitudinally of the axis of substrate **10** to the end of film **11** remote from spine **14.** Correspondingly, the second termination film **13** has a cylindrical spine portion **16** provided in adherent relationship on the other end of substrate **10** and spaced from the resistive film. Such spine **16** is integral with teeth **17** which extend to the remote end of the resistive film. Each spine preferably extends clear to the substrate end.

The termination films **12** and **13** are preferably formed of a silver-ceramic conductive material in a glass matrix, or they may be formed of a silver-epoxy conductive plastic.

Alternatively, but far less preferably, the termination films **12** and **13** may be applied (laminated) under the resistive film **11** instead of over the same. This however, is normally not desired since termination films applied under the resistive film must incorporate very noble metals such as gold, palladium, etc., whereas those applied over the resistive film may incorporate far less expensive metals such as silver. This is because silver termination materials have the characteristic of dispersing into the resistive film **11** if they are applied to the substrate prior to the application and firing of the film **11,** that is to say in underlying (instead of overlying) relationship relative to the resistive film.

As best shown in FIG. **3,** the spacings between the various comb teeth, and the relative orientation of the two combs, are such that the teeth mesh with each other and are substantially equally spaced about the circumference of the exterior surface of resistive film **11.** In the illustrated embodiment, there are three teeth **15** or **17** on each comb **12** and **13,** the teeth of each comb being circumferentially spaced 120° from each other and circumferentially spaced 60° (on centers) from each adjacent comb tooth. It is emphasized, however, that the number and spacings of the teeth may be varied substantially.

The various comb teeth divide the resistive film **11** into a number of parallel-connected resistor elements *a, b, c, d, e,* and *f.* Each such resistor element is wide and short. Because there are a number of parallel connected resistor elements $a-f$, and because each such resistor element is wide and short, the overall resistance value may be made very low despite the fact that the resistive material forming film **11** inherently has a relatively high resistance value.

To state the above in another manner, the "length" of each resistor element, *a, b,* etc., is equal to the circumferential spacing between two adjacent teeth **15** and **17.** This spacing may be a very short distance. The "width" of each resistor element is equal to the dimension of the resistive film **11** longitudinally of the substrate **10.** The various (six in number, in the present example) "wide" and "short" resistor elements $a-f$ thus formed are all connected in parallel-circuit relationship with each other, since each "end" of each such resistor element is electrically connected (via a tooth) to a spine **14** or **16.** With the described relationship, the direction of current flow is circumferential to the resistive film **11.**

The described relationship also results in very low inductance, one reason being that the current paths are wide and short. Also, since the currents flow in opposite directions from (or to) each comb tooth **15** or **17,** the generated magnetic fields may tend to neutralize each other — thus further lowering inductance.

In accordance with the present invention, the various resistor elements $a-f$ (which are defined between and complementary to the respective comb teeth) are so shaped and disposed that the amount of electrical resistance heating at the central region of substrate **10** is much less than the amount of such heating at the end portions thereof. Furthermore, the resistor elements $a-f$ are so shaped and disposed that the overall result of this disuniform heating is that the temperature of the substrate is substantially constant along the length thereof, it being emphasized that there is much more cooling at the end portions of the substrate than at the central region thereof. Very desirably, there is no sharp discontinuity between the central region and the end portions, there being instead a progressive or tapered relationship whereby the amount of heating becomes progressively and smoothly less from the end portions toward the center.

Stated in another manner, and more specifically, each of the comb teet **15** and **17** is, starting at each edge of the resistive film **11**, shaped generally in the manner of a prolate hourglass. That is to say, each of such teeth is (beginning at each edge of film **11**) shaped as a prolate double trapezoid having a common side (the common side being the one opposite the base) at the center of the substrate. (The connector film regions **21** between the inner tooth ends and the adjacent comb spines may be narrow, as in FIGS. **1** and **2**.)

Since the resistor regions $a-f$ are complementary to the comb teeth, each such resistor region is also a prolate double trapezoid but having the base side at the center of the substrate.

All portions of each of the teeth **15** and **17** are circumferentially spaced from all portions of each of the adjacent teeth **15** and **17**. This (as above indicated) means that current, in flowing through the resistive film **11** between a tooth of one polarity and the adjacent tooth of opposite polarity, must flow circumferentially of the resistor. Because of the described shapes of the teeth **15** and **17**, and of resistor portions $a-f$, the circumferential flow distance is much longer at the central region of each resistor portion than at the ends thereof, being progressively less as the ends are approached. Because the resistive film **11** is applied with uniform thickness throughout, it follows that the electrical resistance between adjacent teeth is much less (for a given increment of width, longitudinally of the substrate, of each resistor element $a-f$) near the ends of the substrate than near the center thereof. Conversely, the electrical resistance presented to the circumferentially flowing currents is much greater at the substrate center than near the ends.

Due to the above-described relationships, the current density is lowest near the center of the substrate, greatest near the ends thereof (that is to say, near the edges of the resistive film **11**), and is progressively and smoothly greater as the ends are approached in directions away from the center. The generated heat is a function of the power supplied to any given region of the resistor, and power is (in turn) a function of the square of the current times the resistance. The resistance varies linearly ad is (as noted above) smaller as the end regions are approached. However, since power varies in accordance with the square relationship relative to current, it follows (despite the fact that the resistance is smaller toward the ends) that the amount of electrical power supplied to the end regions of the resistor (near the edges of film **11**) is much greater than the amount of power suppled to the central region of the resistor. Such added power at the ends produces markedly increased heating.

The precise shapes of the teeth **15** and **17**, the spacings therebetween, etc., are empirically selected in such manner that the amount of heating occurring at the central region of the substrate will be sufficiently low, in comparison to the heating occurring at portions remote from the center, that there will not be a hot spot at the center but instead will be a relatively uniform temperature throughout the full length of the substance.

To conduct current to and from the termination films **12** and **13**, cup-shaped end caps **18** and **19** are respectively press fit thereover. Leads **21** and **22** are mechanically and electrically connected to the centers of the respective caps.

The combination of the end caps **18-19** and the termination film spines **14** and **16** causes the contact resistance to the resistor to be predetermined, uniform and stable. Where less accuracy and stability are permissible, the end caps may engage the teeth **15** and **17** directly, the spines **14** and **16** then being omitted. This latter construction is not preferred.

The entire assembly is coated by means of a coating **23** (encapsulating means) formed of a suitable material having the requisite characteristics relative to environmental protection — namely insulating ability, moisture resistance, heat resistance, etc. A preferred coating material is silicone conformal, which may be purchased from Midland Industrial Finishes Company, of Waukegan, I.

In manufacturing the present resistor, the centerless-ground ceramic extrusion **10** is first coated with the above-indicated resistive film **11**. Such coating is preferably effected by silk-screening. To permit the complex oxides in a glass matrix to be silk-screened, they are first mixed with a pine oil (squeegee oil) vehicle. The printed cylinder **10** is then fired in air, in a furnace, at temperatures in excess of 1,400° F., in order to effect melting of the glass and curing of the resistive material. Such firing step is continued for 30 minutes.

As the next step in the method, the termination films **12** and **13** are applied to substrate **10** over the resistive film **11**, again by silk-screening. The cylinder is then again fired, for (for example) 5 minutes at 1,100° F.

Preferably, the silk-screening is effected by the apparatus and method disclosed in my copending patent application Ser. No. 424,810, filed Dec. 14, 1973, for Method and Apparatus for Manufacturing Cylindrical Resistors by Thick-Film Silk-Screening. Said application is hereby incorporated by reference herein, as though set forth in full.

As the next step in the method, the end caps **18** and **19** are press fit over the spine portions **14** and **16** of termination films **12** and **13**. The leads **21** and **22** are then electrically connected to leads in a suitable resistance testing device, such as the one described in the cited copending patent application Ser. No. 456,474. The method described in detail in such application is then performed to abrade (by abrasive blasting) a longitudinal groove 20 (FIG. **4**) in a portion of at least one of the resistor elements $a-f$ defined between adjacent comb teeth, the length of the groove being such as to "trim" the resistor until the precise desired resistance value is achieved (as indicated by an ohmmeter).

In the far less desirable embodiment whereby the termination films are of a type which contain gold or other extremely expensive noble metal, and such termination films underly instead of overly the resistive film **11**, the trimming step is effected by abrading the resistive film **11** as with a suitable lapping cloth.

As the final step in the method, the coating **23** of environmentally protective material is provided, as by spraying of dipping, to complete the product.

The word "resistive," as employed in this specification and claims, denotes a film which (a) is not an electrical insulator, (b) is an electrical conductor, (c) is not a good electrical conductor, and (d) has a substantial amount of electrical resistance.

Throughout this specification and claims, the word "cylinder" is used in its conventional sense (a surface traced by a straight line moving parallel to a fixed straight axis and intersection a fixed circle, the circle lying in a plane perpendicular to the axis, the circle having the axis as its center).

The foregoing detailed description is to be clearly understood as given by way of illustration and example only, the spirit and scope of this invention being limited solely by the appended claims.

I claim:

1. A film-type resistor, which comprises:

a. an elongated cylindrical substrate,

a. a resistive film provided adherently on the cylindrical surface of said substrate,

c. a plurality of termination film strips formed of conductive material,

said termination film strips being adherently provided in at least partially laminated relationship relative to portions of said resistive film,

said termination film strips being elongated and extending in directions generally longitudinally of said substrate,

said termination film strips being spaced relative to each other circumferentially of said cylindrical surface,

said termination film strips defining between them at least one resistor element composed of at least part of said resistive film, and through which currents flow in paths generally circumferential to said substrate,

said resistor element and said termination film strips being so shaped and disposed that said circumferential current paths through said resistor element are relatively long at the central region of said substrate, and relatively short at the end portions thereof, and

d. means to connect one of said termination film strip to one lead and to connect another of said termination film strips to another lead,

whereby when said leads are connected in an electrical power circuit, the amount of electrical heating occurring in said resistive film at said central region of said substrate is substantially less than the amount of such heating occurring at said end portions.

2. The invention as claimed in claim **1**, in which said resistive film is uniform in thickness.

3. The invention as claimed in claim **1**, in which each of said termination film strips is relatively wide adjacent each end portion of said substrate, is relatively narrow at the central region of said substrate, and becomes progressively wider in both directions away from said central region.

4. The invention as claimed in claim **3**, in which each of said termination film strips is a prolate double trapezoid having a common side, said common side being at said central region of said substrate, the two bases of said double trapezoid being remote from said central region.

5. The invention as claimed in claim **1**, in which the shapes and positions of said termination film strips are such that, when said leads are connected in an electrical power circuit, the resistive heating causes the temperature of said resistor to be substantially uniform along the length of said substrate.

6. The invention as claimed in claim **1**, in which said means recited in clause (d) comprises metal end caps respectively mounted over opposite ends of said substrate, one of said end caps being electrically connected to said one of said termination film strips and to said one lead, the other of said end caps being electrically connected to said other of said termination film strips and to said other lead.

7. The invention as claimed in claim **6**, in which said resistive film is not present on the end portions of said substrate beneath said end caps, and in which said means recited in clause (d) comprises two additional termination films formed of highly conductive material, one of said additional termination films being provided adherently on said substrate beneath said one end cap and being connected integrally to said one termination film strip, the other of said additional termination films being provided adherently on said substrate beneath said other end cap and being connected integrally to said other termination film strip.

8. The invention as claimed in claim **1**, in which said resistive film is one resulting from the silk-screening of resistive material onto said sustrate.

9. The invention as claimed in claim **1**, in which said substrate is solid, not hollow, and is formed of ceramic.

10. A relatively low resistance cylindrical film-type resistor having substantially uniform temperature characteristics, which comprises:

a. an elongated cylinder forming a substrate,

b. a uniform-thickness resistive film provided adherently on the exterior cylindrical surface of said substrate,

said film being substantially tubular and having end regions which are respectively spaced from the ends of said substrate,

c. first termination film means provided adherently on said substrate,

said first termination film means being generally comb shaped in that it has spine means at one end of said substrate and spaced from the corresponding end region of said resistive film, and furthermore has elongated tooth means extending longitudinally of said substrate in circumferentially-spaced relationship about said exterior cylindrical surface,

said tooth means being laminated relative to said resistive film,

d. second termination film means provided adherently on said substrate,

said second termination film means being generally comb shaped in that it has spine means at the other end of said substrate and spaced from the corresponding end region of said resistive film, and furthermore has elongated tooth means extending longitudinally of said substrate in circumferentially-spaced relationship about said exterior cylindrical surface,

said tooth means being laminated relative to said resistive film,

said tooth means intermeshing said tooth means of said first termination film means in circumferentially spaced relationship, said tooth means of said first and second termination film means being so shaped and located, and the portions of said resistive film between said tooth means being so shaped and located, that currents flowing through said resistive film generally circumferentially of said substrate, between adjacent ones of said tooth means, must flow relatively long distances at the central region of said resistive film, and relatively short distances at the end portions thereof, and

e. electrical connector means connected to said spine means at opposite ends of said substrate.

11. The invention as claimed in claim **10**, in which each of said tooth means of each of said termination film means is relatively wide adjacent each end region of said resistive film, is relatively narrow adjacent the central part of said resistive film, and progressively narrows in directions from each of said end regions toward said central part.

12. The invention as claimed in claim **10**, in which the shapes and locations of said tooth means are such as to cause electrical heating of said substrate to a substantially uniform temperature along the length thereof.

13. The invention as claimed in claim **10**, in which each of said tooth means is shaped generally as a prolate double trapezoid the bases of which are respectively adjacent said end regions of said resistive film, the sides opposite said bases being coincident with each other and being at the central part of said resistive film.

14. The invention as claimed in claim **13**, in which said tooth means divide said resistive film into a plurality of circumferentially spaced resistor elements, each of which is shaped generally as a prolate double trapezoid having a common base at the central part of said resistive film.

15. The invention as claimed in claim **10**, in which each of said tooth means is generally hourglass-shaped.

16. The invention as claimed in claim **10**, in which at least one of said tooth means is relatively wide adjacent each end region of said resistive film, and relatively narrow adjacent the central part of said resistive film.

17. The invention as claimed in claim **10**, in which said electrical connector means recited in clause (e) comprises conductive end caps mounted over said spine means at opposite ends of the resistor.

18. The invention as claimed in claim **10**, in which said tooth means overlie said resistive film in adherent relationship thereto.

19. The invention as claimed in claim **18**, in which a groove is provided in said resistive film between adjacent ones of said tooth means, the length of said groove being such as to cause said resistor to have a desired resistance valve.

20. A cylindrical resistor having uniform temperature characteristics, and having a low resistance value, which comprises:

a. an elongated cylindrical substrate,

b. a plurality of elongated resistive film elements adherently provided genrerally longitudinally on said substrate in circumferentially spaced relationship thereabout,

said elements having relatively long dimensions circumferentially of said substrate at the central region thereof, and having relatively short dimensions circumferentially of said substrate at the end portions thereof, and

c. termination means to connect said resistive film elements in parallel-circuit relationship relative to each other and also in such manner that the current flow paths through each of said resistive film elements are generally circumferential to said substrate,

whereby the amount of resistive heating occurring at said central region is less than at said end portions.

21. The invention as claimed in claim **20**, in which said circumferential dimensions change progressively along the length of said resistive film elements.

22. The invention as claimed in claim **20**, in which the shapes and location of said resistive film elements are such that the temperature of said substrate is substantially constant along the length thereof.

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