June 3, 1947.

S. O. DORST

2,421,688

NONINDUCTIVE RESISTANCE ELEMENT

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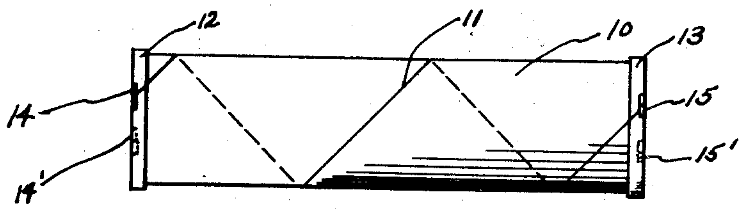


FIG. 1

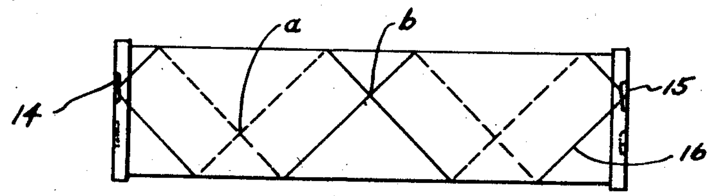


FIG. 2

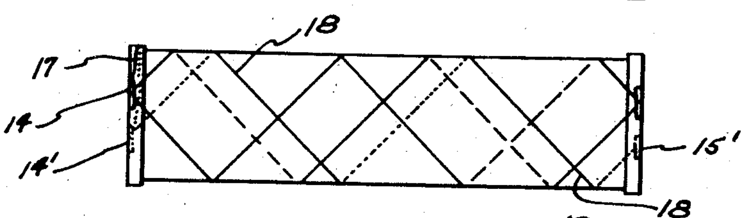


FIG. 3

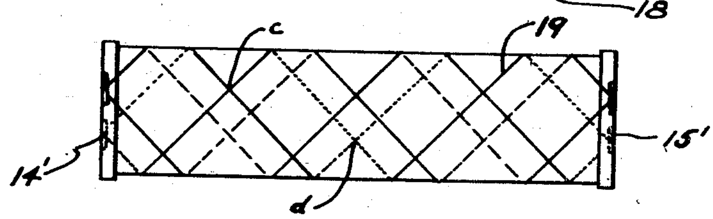


FIG. 4

FIG. 5

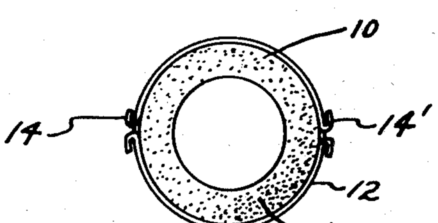
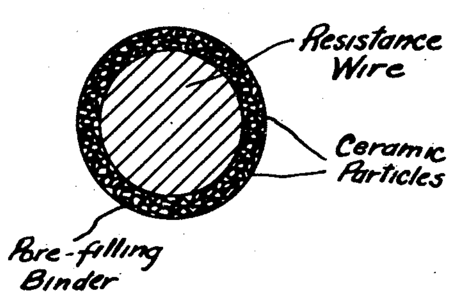


FIG. 6



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NONINDUCTIVE RESISTANCE ELEMENT

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6 Claims. (Cl. 201—67)

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This invention relates to improved resistance elements and more particularly to high frequency non-inductive resistance elements.

For most precision work resistance elements are constructed of wire wound about a ceramic, or glass, or resin core with air spaces between adjacent turns. These resistors possess substantially constant resistance values over the range of frequencies normally met in operation. However, at radio and higher frequencies a plain wire wound resistor of the single or multiple layer solenoid type is very likely to act as though it were a circuit shunted by a capacitor or in series with an inductance element. Due to the nature of the winding certain of the turns of the resistor may not be neutralized inductively by other turns of the resistor as, for example, in a conventional solenoid type wire wound resistor.

To offset the undesirable effect of inductance at high frequencies a special type of winding was developed many years ago. This is known as the Ayrton-Perry winding. This winding consists of two resistance wires in parallel wound in counter directions so that the counter turns overlap each other at two points per turn and partially neutralize the inductive field covered or induced in each turn. However, there is considerable inductance in this type of winding at high frequencies such as 5 megacycles, particularly when used on high wattage resistors. This inductance is due to the fact that it is not possible to obtain a complete cancellation of the inductive field of one turn by its counter turn in the opposite direction, because this counter turn overlaps the first turn at two points around the circumference causing part of the field of the counter turn to be outside the circumscribed area and field of the first turn. Inasmuch as this residual inductance in each turn is additive, the residual inductance of the resistor increases with the number of turns therein. Further, the outer wire turns are of greater diameter and hence possess more inductance per turn. Up until this time, no pronounced advancement has been made on the Ayrton-Perry winding.

Several methods have been devised whereby this unneutralized inductance is reduced to a smaller value. The first of these is to reduce the number of turns in the resistor. The second is to use a very fine wire, a higher resistance value per turn being obtained with a thinner wire. A third method is to use a resistor core of large diameter and relatively short lengths. This as in the first method will reduce the number of turns. A fourth and frequently used method is

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to employ flat rectangular or square resistance cores rather than the conventional round core. Unfortunately, however, all of these methods of reducing residual inductance severely limit the wattage which may be dissipated per unit volume of resistor and also limit the ability of the resistor to withstand overloads. Further, while the residual inductance is reduced, it is not lowered sufficiently to enable the resistor to be used satisfactorily at ultra high frequencies.

Due to the foregoing and related defects these prior art resistors are not suitable for the following purposes, as well as many others: dummy antennas for testing high frequency transmitters; high frequency and pulse network terminations; transmission line matching loads; antenna matching loads; and voltage dividers for pulse measuring circuits. As far as is known, no resistor has heretofore been made which could satisfactorily be used for these purposes, in high frequency ranges, e. g. above 10 megacycles per second.

It is an object of this invention to produce new precision type resistors. It is a further object to produce precision resistance elements which possess the advantages of prior precision resistors without at the same time being subject to their disadvantages. It is a further object to produce wire wound precision type resistors which exhibit negligible residual inductance effects at high frequencies. It is a further object to produce precision wire wound resistors, operable at high temperatures without insulation failure. Additional objects will become apparent from a consideration of the following description and claims.

In accordance with the invention precision wire wound resistors are produced employing at least two mutually coupled out of phase sets of parallel windings which in themselves possess small mutual and series inductance. In a more restricted sense this invention is concerned with a precision wire wound resistor comprising at least two pairs of resistance wires connected in parallel, the wires of each pair being wound in opposite directions and the pairs being sufficiently out of phase to substantially neutralize the inductance thereof. In a still more restricted sense, the invention is concerned with a resistor comprising a core upon which is wound at least two pairs of superposed resistance wires connected in parallel to the extremities of said core, the wires of each pair being wound in opposite directions and the pair being sufficiently space wound out of phase to substantially neutralize the inductance thereof.

According to one of the preferred embodiments of the invention there is produced a resistor comprising a core upon which is wound at least two pairs of superposed resistance wires covered with a thin coating of insulating material, said wires being connected in parallel, the wires of each pair being wound in opposite directions, and each pair of wires being radially displaced with respect to every other pair.

According to one of the specific embodiments of the invention, there is produced a resistor comprising a core upon which is wound two pairs of superposed resistance wires covered with a thin coating of insulating material, said wires being connected in parallel, the wires of each pair being wound in opposite directions, and one pair of wires being radially displaced approximately 180° from the other pair.

According to one of the limited embodiments of the invention, the resistors described herein are provided with a coating of a moisture resistant resinous material, to produce a durable, small-volume resistor, particularly adapted to high-frequency operation in corrosive atmospheres.

In order to produce precision wire wound resistors which possess negligible residual inductance in the turns and in the aggregate resistor, I have found that an unusual type of winding is required. In general, the procedure for obtaining this winding is as follows:

The usual ceramic or molded core is mounted on a rotating axis. Terminal bands each with two terminal ears displaced on the core approximately 180° apart are affixed to each extremity of the core. The resistance wire is connected to one terminal ear and the winding begun. As the core rotates the wire is wound at a constant rate toward the other extremity. When it reaches this extremity, it is attached to the corresponding terminal ear thereon. Then it is wound back at the same lateral rate toward the former extremity, with the core rotating in the same direction. This second winding crosses over the first at approximately 180° intervals, so that the turns of the second winding partially neutralize the inductance in the turns of the first winding. When the original terminal ear is reached the wire is connected thereto. It is then passed to the other terminal ear, on the opposite side of the same terminal band. A third layer is then wound similarly to the first layer, being started at the terminal ear located approximately 180° around the core from the ear used at the start of the first layer. When the wire of the third layer reaches the other terminal band at the second terminal ear thereon, it is connected and a fourth layer wound back therefrom toward the original terminal in the same manner as the second layer, being started from the ear 180° around the core from the ear from which the second layer started. During this winding all the layers are thus connected in parallel between end terminals.

The wire employed for the winding is preferably a high resistance alloy such as nichrome, which possesses a small temperature coefficient of resistance. I have found that optimum results may be achieved only when the wire insulation is very thin. The thickness of the insulation usually should be less than one mil and preferably less than one-half mil. In accordance with a preferred embodiment of the invention, I employ a resistance wire provided with flexible, refractory ceramic insulation of approximately one quarter mil thickness. This invention will withstand the effects of continual operation at elevated temperatures without appreciable deterioration, and at the same time permit the manufacture of resistors possessing negligible inductance at high frequencies.

Resistors formed in accordance with the above instructions will possess substantially negligible residual inductance, apparently because of several factors. First, because the residual inductance of the first and second and of the third and fourth windings is in parallel, thereby reducing the value of the total residual inductance. Secondly, the uncancelled inductive fields of the first and second layers are substantially neutralized by the uncancelled fields of the third and fourth layers. A third factor is that the difference in the diameter per turn of the various layers has been reduced to a negligible value, by the use of insulation of heretofore unattainable thinness. The resistor thus designed has a uniform winding as well as a distributed heat dissipation over the core because of the layers falling between each other even though said layers are space wound. Furthermore, since there are four layers in parallel it is possible to use a smaller size wire, which in turn will help reduce the residual fields. In addition, the insulation permits high operating temperatures and voltages.

The invention is not restricted to the use of only four resistance layers inasmuch as desirable results may be obtained by the use of 6, 8, 10 or more layers. However, the design of a resistance element using six layers or more may be somewhat different. For example, if there are eight layers the difference between the starting points of the sets of layers may be approximately 90° instead of approximately 180°. In like manner, if only six layers are employed the difference in the starting point of any two layers may be approximately 120° instead of approximately 180°.

The phrase "out of phase" appearing herein may be defined for the purposes of this invention as the different starting and ending points of sets of parallel windings. For example, if the second set of windings (e. g. two wires) is started at a point approximately 180° about the resistor core from the starting point of the first set, the sets of windings would be 180° out of phase. Alternate expressions which might be used are "radially displaced windings," "radially varied starting points," and "radially varied crossing points."

By reference to the appended drawings, the invention will be further described.

Figure 1 is a plan view of the resistor after the first layer is wound;

Figure 2 is a similar view after the second layer is wound;

Figure 3 is a similar view after the third layer is wound;

Figure 4 is a similar view after the fourth layer is wound to produce the finished resistor;

Figure 5 shows an end view of the resistor of Figure 4;

Figure 6 shows a cross-section of the insulated resistor wire.

Referring more specifically to Figure 1, 10 is a cylindrical ceramic core of steatite, porcelain, etc., similar to those used in conventional wire wound resistors. 12 and 13 represent terminal bands of tinned copper or other conducting material, affixed to the core by clamping, pressing or other standard means. These bands extend circumferentially around the core 10, and are provided with terminal ears or connectors 14 and

14', and 15 and 15' respectively. These terminals permit the wire to be wound about the core without slippage. Terminal ears 14 and 15 are located in the same radial plane, and terminal ears 14' and 15' are likewise located in the same radial plane, approximately 180° from the plane of terminal ears 14 and 15 (on the opposite side of the core). All ears are located in the same diametrical plane. The first layer of wire 11, which is wound progressively from terminal 14 to terminal 15, is shown as a continuous line on the visible side of the core 10, and as a broken line on the far side.

Referring now to Figure 2, the wire which is designated as 16 in the second layer is wound back from terminal 15 in the opposite direction with the core turning in the same direction as when the first layer was wound. When the wire reaches terminal ear 14 it is attached to it. It will be noted that the wires cross twice, at *a* and *b* during any one complete turn of each wire, approximately 180° between crossings.

Referring now to Figure 3, the wire 17 may be led from ear 14 along band 12 for 180° and is attached to ear 14' on the opposite side of the core 10. From this point the wire is wound about the core in the same direction as the first layer (the core rotating in the same direction as for the two preceding layers). In this layer the wire is represented as 18, and is shown as a dotted line on the far side of the core. When the wire reaches the other end of the core, it is attached to ear 15', 180° around the core from ear 15. It is apparent that wire 17 may be dispensed with if desired, since band 12 is a conductor.

Referring now to Figure 4, wherein the wire for the fourth layer is designated as 19, this layer is wound from terminal ears 15' and 14' in the same manner as the second layer 16. For any one complete turn of layers 18 and 19, the wires cross twice, as indicated by *c* and *d*. It appears that the residual inductance of layers 11 and 16 is neutralized, at least in part, by the residual inductance of layers 18 and 19, when the two sets of layers are approximately 180° out of phase.

If, for example, the core were $9\frac{5}{16}$'' between terminals and ⅝'' diameter, a 62.5 ohm resistance element rated at 120 watts could be produced, employing a #36 ceramic coated nichrome wire (the insulation thickness being one quarter mil per side) with 90° turns per layer and a total of four layers. This resistance element would possess an inductance of under one-half microhenry at 10 megacycles per second.

While comparison of the novel resistors described herein with the usual other non-inductive resistors is difficult, since the structures are different, some indication of the advantage may be realized by the following data:

A two wire resistor utilizing the Ayrton-Perry winding and having a resistance of 62.5 ohms with a 120 watt rating (two wires) possessed an inductance of about 1.22 microhenries at 10 megacycles per second, more than double the inductance of the example cited above. If #36 nichrome wire and fewer turns are employed, the desired wattage cannot be realized, without going beyond the maximum current-carrying capacity of the wire.

It is possible to vary the radial phase relationship without increasing the inductance to an undesirable value. Even if, as in commercial production, the sets of layers are terminally connected at 160° or even 140° radial differences, the inductance remains below 1.0 microhenry at high frequencies, such as 10 megacycles. Thus, while a 180° phase displacement between sets of windings gives optimum results, very satisfactory and highly improved resistors may be produced with phase displacements varying therefrom, particularly 90° or more.

Figure 5 shows an end view of the resistor of Figure 4, illustrating the appearance of the terminals. 10 represents the resistor core, about which terminal band 12 is placed. 14 and 14' are terminal ears, which may be raised portions of the band 12, stamped out before positioning of the band on core 10. If resinous coatings are employed, terminal ears 14 and 14' may act as terminals for connecting the resistor into the circuit or an additional terminal extension may be provided in the customary manner.

Figure 6 shows a cross-section of the resistance wire employed in accordance with one of the preferred embodiments of the invention. This wire may be of nichrome, nickel, tungsten or other metal or alloy, preferably having high resistance. The ceramic particles may be of china clay, talc, zinc oxide, titanium dioxide, silica, ground mica or other refractory materials, or mixtures thereof.

Suitable methods for producing refractory insulated conductors particularly adapted for use herein are disclosed in copending applications Serial No. 472,465, filed on January 15, 1943, by S. O. Dorst; Serial No. 496,978, filed on August 2, 1943, by P. Robinson and S. O. Dorst and Serial No. 536,448, filed on May 20, 1944, by S. O. Dorst.

I have found that to reduce the residual inductance of the resistors of the invention to negligible amounts, the thickness of the insulation should usually be less than one mil and is preferably less than one-half mil. By this expedient, the use of several layers of wire does not introduce appreciable additional inductance due to the greater diameter (and length) of the outer turns. However, the use of glass-fibre-covered wire and other high temperature insulation in conjunction with the specific type of resistor winding disclosed herein is also contemplated by the present invention. Resistors of this type also possess low residual high frequency inductance, particularly when the insulation is less than two mils thick.

It is apparent from the preceding description that the invention is not limited to ceramic insulation or to thicknesses less than one mil, but also embraces resistance wires insulated with other materials, for example, glass-fibre; polyvinyl resins such as poly-tetrafluoroethylene, polyethylene, polydichlorostyrene, etc; resins of the hydrolysis products of alkyl-, aryl-, and/or aralkyl-chlorsilanes; non-conducting metal oxides, etc. Highly satisfactory results may be achieved by polymerizing the aforesaid and related resins in the pores and on the surface of the ceramic insulation before or after winding. After the resin has served its purpose it may be burned off, if desired.

Following winding of the resistor unit, the core and wire may be provided with a suitable enclosure in the customary manner. For a hermetically sealed unit, the construction disclosed in U. S. Patent 2,332,255 is particularly desirable. The resistor may also be placed in a ceramic tube, leads provided for the end terminals and the enclosing tube ends sealed with a moisture and temperature resistant cement.

In accordance with one of the preferred embodiments of the invention, the resistor of Figure 4 is provided with a moisture resistant, heat-resistant resinous coating, which obviates the necessity of sealing the resistor in a bulky ceramic or glass tube. To accomplish this the wound element is dipped in a monomer or partially polymerized mass of a hydrolysis product of an alkyl-, aryl-, and/or aralkyl-chlor-silane, sometimes referred to as silicones. It may then be hung by the terminals in an oven at elevated temperatures (e. g. 150° C. to about 300° C.) to effect polymerization or curing. Additional coatings may be applied, if so desired, by the same procedure. Solvents may be employed to maintain a low viscosity in the partially polymerized resin.

I generally prefer an average coating thickness of about 30 mils, but satisfactory results have been obtained with coatings of from about 10 mils average thickness to more than 50 mils average thickness. A resistor produced in accordance with the instructions given above, with an average coating thickness of about 30 mils of a resin of the above type, will not fail on repeated salt immersion and thermal shock tests, as well as being operable at elevated temperatures, e. g. 200° C., for long periods of time without failure. The combination of this type of resin with the ceramic coated resistance wire is particularly advantageous.

It will be apparent that the structure defined as a preferred embodiment of the invention may be applied on rectangular cores, flat cores, or other types of cores used in the art. Further, the terminal bands may be provided with a die-cast band of solder or other low-melting alloy, following winding of the resistor. Likewise, other modifications of the described resistors, well known to those familiar with this art, may be incorporated therein.

As many widely different embodiments of this invention may be made without departing from the spirit and scope hereof, it is to be understood that the invention is not limited to the specific embodiments hereof except as defined in the appended claims.

I claim:

1. A resistor comprising a core upon which is wound two pairs of superposed resistance wires covered with a thin coating of insulating material, said wires being connected in parallel, the

wires of each pair being wound in opposite directions, and one pair of wires being radially displaced approximately 180° from the other pair.

2. A resistor comprising a core upon which is wound two pairs of superposed resistance wires covered with a ceramic coating less than one mil thick, said wires being connected in parallel, the wires of each pair being wound in opposite directions and one pair of wires being displaced approximately 180° from the other pair.

3. The resistor of claim 2 enclosed within a coating of moisture resistant resinous material.

4. The resistor of claim 2 enclosed within a coating of moisture-resistant resinous material comprising a polymer selected from the class consisting of the hydrolysis products of the aryl-, aralkyl- and alkyl-chlor silanes.

5. A resistor comprising a core upon which is wound a plurality of pairs of superposed resistance wires covered with a thin coating of insulating material, said wires being connected in parallel, the wires of each pair being wound in opposite directions, and each pair of wires being radially displaced from each adjacent pair by at least 90°.

6. A resistor comprising a core upon which is wound three pairs of superposed resistance wires covered with a thin coating of insulating material, said wires being connected in parallel, the wires of each pair being wound in opposite directions and each pair of wires being radially displaced approximately 120° from each of the other pairs.

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