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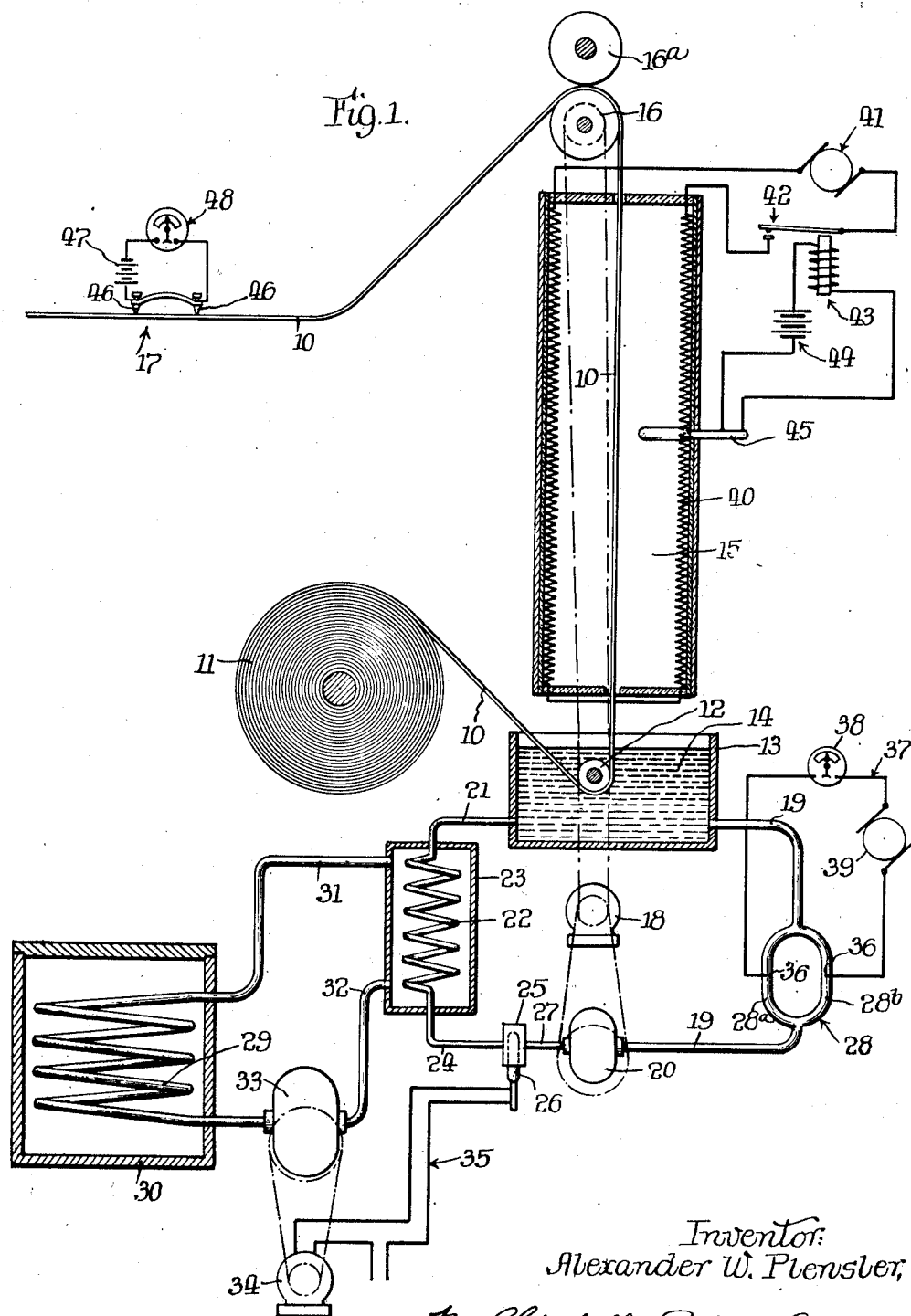
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2,138,938

ELECTRICAL RESISTANCE AND PROCESS OF MAKING SAME

Filed Nov. 1, 1933

2 Sheets-Sheet 1



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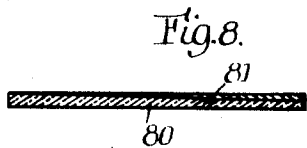
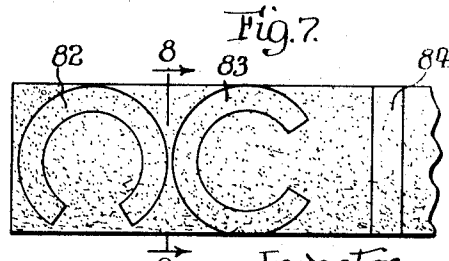
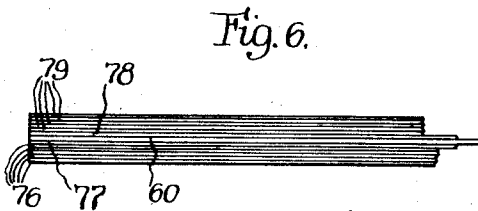
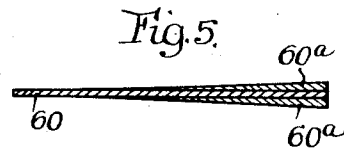
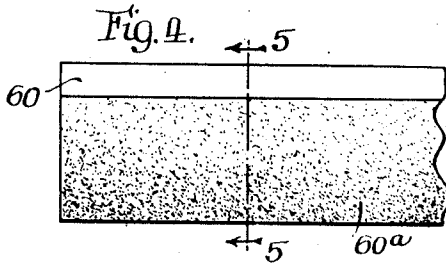
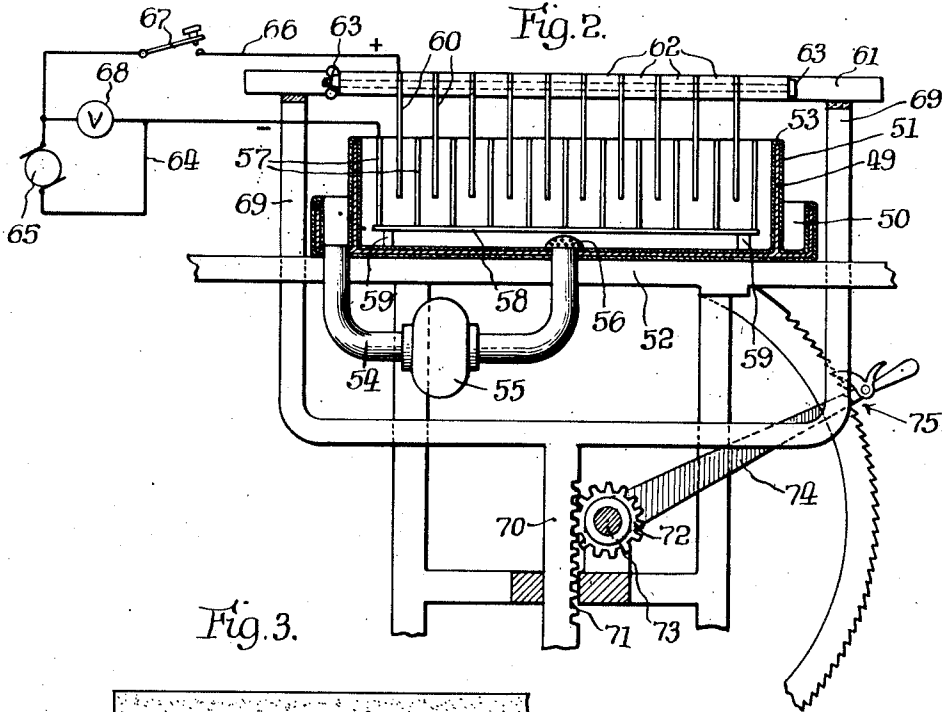
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2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

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ELECTRICAL RESISTANCE AND PROCESS OF MAKING SAME

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Application November 1, 1933, Serial No. 696,166

6 Claims. (Cl. 201—76)

The invention relates generally to electrical resistances and the process of making same and in particular has reference to resistances which embody a compact mass of resistance material as distinguished from resistances utilizing a wire or similar resistance material.

An object of the invention resides in the provision of an improved electrical resistance by a novel process, which resistance is durable, wear resisting, is not materially affected by temperature or humidity variations, which permanently retains its original resistance characteristics and in operation does not create electrical noise.

Another object is to provide a novel process of producing resistances whereby uniformity of the resistances within a very narrow tolerance limit may be obtained.

A further object is to provide a process which embodies the step of combining a strip of resistance material with a mass of electrically deposited resistance material to form a complete resistance element having predetermined resistance characteristics.

Another object is to provide a novel process which embodies the step of electrically producing a resistance mass having predetermined characteristics throughout various portions of its area.

Still another object of the invention is to provide a novel process of electrically producing a mass of resistance material in such manner that the thickness of the mass is tapered from one edge to an opposite edge with a carefully controlled variation in thickness so as to adapt the mass of resistance material for use in an electrical resistor having non-linear resistance characteristics.

In conjunction with the foregoing, another object is to produce such a mass by electro-deposition and thence to transfer said mass together with a layer of graphite impregnated paper to a dielectric base. Preferably this aim is attained during and by a step of incorporating the mass and the impregnated paper section in a base impregnated with an uncured phenol condensation product while curing said product.

Another object is to provide an improved resistance unit embodying a resistance element formed of separate sections which are intimately combined into a single element in the act of mounting the element on a dielectric base.

Other objects and advantages will become apparent in the following description and from the accompanying drawings, in which:

Figure 1 is a diagrammatic view of an apparatus for performing certain steps of the invention.

Fig. 2 is a similar view of apparatus for performing other steps of the invention.

Figs. 3 and 4 are plan views of resistance formed by the apparatus shown in Figs. 1 and 2 respectively.

Fig. 5 is a sectional view taken along the line 5—5 of Fig. 4.

Fig. 6 is a side elevation of an assembly of parts including the resistances shown in Figs. 3 and 4.

Fig. 7 is a plan view of a completed resistance and illustrates the manner in which separate elements are obtained therefrom.

Fig. 8 is a sectional view taken as indicated by the line 8—8 of Fig. 7.

While the invention is susceptible of various modifications and alternative constructions, I have shown in the drawings and will herein describe in detail the preferred embodiment, but it is to be understood that I do not thereby intend to limit the invention to the specific form disclosed, but intend to cover all modifications and alternative constructions falling within the spirit and scope of the invention as expressed in the appended claims.

In the production of electrical resistances which are formed from a mass of resistance material, many difficulties are encountered which are not met in a resistance embodying a resistance wire or the like. It is, for example, exceedingly difficult to form a mass of resistance material, and particularly material which is finely divided or comminuted, into resistance elements which have any degree of uniformity. In quantity production such uniformity within quite narrow limits of tolerance is necessary.

By the present process it is possible to produce, in large quantities, resistance units which are uniform to an unusual degree. Briefly, and more or less particularly stated, the present process embodies the production of a resistance element in several complete sections, each of which has predetermined resistance characteristics. During the formation of each section, the process by which it is produced is accurately controlled so that any part of the section, which may be designated and measured as a unit, will be identical with every other similar unit part. After the several sections have been completed they are assembled and united to form a single resistance unit which has the desired and predetermined characteristics.

Referring more particularly to the process of forming a completed resistance unit, one section

thereof, which will hereinafter be termed, for convenience, the "paper section", comprises a sheet of absorbent material which has been treated so that the sheet carries in intimate association finely divided resistance material. Preferably this end is accomplished by immersing a sheet of absorbent material in a bath containing finely divided particles of a selected resistance material. A preferred material is graphite suspended, in a colloidal state, in an aqueous solution, and throughout the following particular description of the invention the resistance material will be considered as being graphite.

Many types of absorbent material may be used but it is preferred to employ a fine or good grade of absorbent paper. For the sake of uniformity, the paper should be of even texture throughout as every variation in texture has been found to affect the resistance characteristics of the ultimate unit. Moreover the paper should be of ample strength to prevent stretching thereof when wet. After the sheet has been immersed in the solution, it is dried to complete formation of the section. In quantity production uniformity of texture of the absorbent material becomes important in order to avoid variation between unit parts of the section. By "unit part" is meant the portion of a piece of resistance which is selected for comparative test to ascertain possible variation.

The preferred manner of forming the paper section in quantity comprises passing an endless strip of absorbent material through the graphite bath, from which the strip is passed through a drier and then cut into lengths suitable for handling in subsequent steps of the process.

It has been discovered that several factors must be controlled to obtain complete uniformity of result. These factors may be set out in the order in which they are encountered as the strip undergoes treatment. First, as has been mentioned, the absorbent material must be of regular or even texture. Second, the concentration of graphite in the bath must be maintained constant and this includes agitation of the bath to avoid a greater concentration of graphite in one part of the bath than in another part. Third, the temperature of the bath must be maintained constant. Fourth, passage of the absorbent material strip through the drier must be at a uniform rate of speed. Fifth, the material must be dried at a constant temperature. If all of these factors are observed and the control of each factor maintained constant within relatively narrow limits of variation, the resistance characteristics of the resultant strip per unit part will be uniform.

In Fig. 1 of the drawings, mechanism has been diagrammatically illustrated for producing the paper section with uniformity. Therein, 10 designates a strip of absorbent material which passes from a supply roll 11 about a roller 12 located in a container 13 for the graphite bath 14. From the bath, the strip passes through a drying chamber 15, thence about another roller 16 to a final testing and cut-off station designated generally at 17. Any suitable means for feeding the strip through the mechanism at a constant rate of speed may be provided and, as herein illustrated, the motor 18 drives the roller 16 and a presser roll 16^a provides traction. The level of the bath 14 in the container 13 is, in this embodiment, manually maintained at a substantially constant level.

The temperature control and regulation of

the bath may be accomplished by a recirculating flow system which also serves to maintain a uniform dispersion of the particles in the bath. This flow system may also be arranged to facilitate testing of the bath in the operation of controlling the concentration of graphite. As herein illustrated, the system includes a duct 21 which communicates with the container 13 and is connected with a coil 22 located in a closed heat transfer casing 23. The other end of the coil is connected to a pipe 24 which leads to a housing 25 in which a thermally responsive device 26 is mounted. From the housing another pipe 27 leads to the intake side of a pump 20. This pump may be driven by the motor 18. The outlet side of the pump communicates with a conduit 19 which leads to the container 13. Intermediately the conduit 19 has a branched section 28 for a purpose to be presently described.

It has been found advisable to maintain the temperature of the bath 14 below room temperature and the casing 23 is therefore connected with a source of a cooling material. A simple cooling system comprises a coil 29 located in a suitable refrigerating compartment 30 and connected by conduits 31, 32 with the casing 23 to supply cooling fluid thereto. A pump 33 is interposed in the conduit 32 for delivering cooling fluid to the casing 23 whenever it is required, this pump being driven by a motor 34. An electrical circuit 35 for operating the motor is controlled by the thermally responsive device 26. It is preferred that the device 26 be of the type which is quite sensitive to temperature changes to make or break the motor circuit upon relatively small variations of temperature. The cooling system which has been described is effective to hold the temperature of the bath substantially constant. The pump 20 is always running, while the machine is in operation, whereby any variation of temperature in the bath is immediately detected by the thermally responsive device 26 to correct the variation. Moreover, the bath is constantly agitated by the recirculating flow, thus producing uniform dispersion of graphite throughout the bath.

The branching section 28 of the conduit 19 forms a part of a testing system for detecting a variation in the concentration of the graphite in the bath. Thus, each leg 28^a and 28^b of the branched section has a contact terminal 36 mounted thereon and extending into the path of fluid flowing therethrough. These terminals are a part of an electrical circuit 37 which includes a power measuring device, such as an ammeter 38, and a source of power, such as an alternating current generator 39, connected in series. The circuit is completed across the terminals 36 through the resistance material flowing through the branched conduit 28. The ammeter 38, therefore, measures the resistance of the material flowing through the branched conduit and any variation of such resistance from a predetermined value indicates at once that the concentration of resistance material in the bath has varied. By adding additional fluid containing a greater or lesser concentration of resistance material as required, the bath may be held at a predetermined concentration. It is essential that the source of power 39 be an unvarying one and a generator is, therefore, preferred. Moreover, it is quite desirable to use alternating current to avoid plating one of the contact terminals 36 with an electrical deposit of resistance material.

Any suitable means for heating the drying

chamber 15 may be employed as long as the temperature within said chamber may be accurately controlled. Electrical heating elements 40 are used in this instance and are connected for energization from a source of current 41 by a circuit which includes a relay switch 42. An electromagnet 43 for controlling the switch 42 is connected in a circuit which includes the source of power 44 and an accurate circuit controlling thermally responsive device 45 disposed for actuation by temperature changes within the chamber 15. The temperature within the chamber 15 may, by the system just described, be held against greater variation than a few tenths of one degree.

As the strip 10 emerges from the drying chamber 15 it is completely dried and passes to the test and cut-off station 17 where it is cut into even lengths for subsequent use as will be presently described. These lengths comprise the paper sections and a fragmentary face view of a section may be seen in Fig. 3. Preferably a final test to detect possible variation of resistance characteristics within the strip is given at the station 17 to unit parts of the resistance strip selected at random. To this end, spaced contacts 46 are provided at the station 17 for movement into engagement with the strip 10. The contacts are insulated from each other and are spaced a definite and unvarying distance apart. The contacts are connected in a circuit which includes an unvarying source of power 47 and a power measuring device 48. As long as the power from the source 47 does not vary, the resistance across a unit part of the strip 10 (which unit part is predetermined by the portion thereof extending between the two contacts 46) may be checked at random and any variation of resistance immediately ascertained.

Thus, the paper sections may be produced in quantity. Any variation of the resistance characteristics thereof may be immediately noted and corrective measures taken.

The other section of the resistance element comprises a mass of substantially pure resistance material, such as graphite, so formed that it may be incorporated with the paper section to produce the completed unit. This section will, for convenience, be termed the graphite section and the process by which it is formed is preferably one by which a tapered resistance element may be formed. Tapered resistance is a term used in connection with variable resistance and as used herein means generally that the resistance characteristics vary irregularly per unit of length of the resistor instead of regularly.

For example, the following specification is of a 500,000 ohm tapered variable resistor.

	Ohms
The starting end of the resistance 0.....	500
$\frac{1}{8}$ of the overall length.....	1200
$\frac{1}{4}$ of the overall length.....	2900
$\frac{3}{8}$ of the overall length.....	9000
$\frac{1}{2}$ of the overall length.....	16,250
$\frac{5}{8}$ of the overall length.....	38,500
$\frac{3}{4}$ of the overall length.....	90,000
$\frac{7}{8}$ of the overall length.....	215,000
The overall resistance.....	500,000

These resistance variations are produced by proportioning the mass of graphite in the graphite section properly to increase or decrease the resistance of the completed unit at different points. The formation of the graphite sections, therefore, must be accurately controlled to produce, not only desired but unvarying results. In

this embodiment of the invention it is preferred to produce the graphite section by the electro-deposition of graphite and to so control such deposition that varying deposits of graphite occur throughout the section, thereby producing the desired taper of the resistance. This deposition process in which particles of the colloidal dispersion of graphite are deposited on one of the electrodes by the passage of an electric current through the electrolyte may be conveniently termed "electrophoresis".

Referring particularly to Fig. 2, a suitable apparatus embodying an electrophoretic cell for carrying out this step of the process is shown. 49 indicates a receptacle or pan for the electrolyte which contains the resistance material. Finely divided graphite is preferred and will be considered as exemplary of the resistance material. If colloidal graphite in aqueous solution is employed, the solution will serve as the electrolyte to deposit the graphite therefrom. The pan 49 is of substantial dimensions, is relatively shallow and has an encircling trough 50 about its peripheral wall. The pan is suitably insulated as by a coating 51 of enamel or other dielectric material. The pan is so supported upon a base 52 that the upper edge 53 thereof is level. A conduit 54 establishes communication between the trough 50 and a central portion of the pan 49, and a pump 55 is interposed therein to produce a flow from the trough to the pan. A suitable flow distributor 56 is preferably mounted at the pan-end of the conduit to cause a flow of fluid uniformly in all directions from the conduit.

In operation the pan is filled to overflowing with graphite electrolyte and an excess of the electrolyte is provided in the trough whereby operation of the pump produces a recirculating flow from the trough to the pan and thence over the upper edge of the pan into the trough. Since the pan is level, the overflow is uniform over the entire upper edge. The ultimate aim of this arrangement of parts is to produce an upper surface level of electrolyte which is at a definite and constantly maintained point with respect to the rest of the apparatus.

While only a single set of terminal or electrode elements may be employed, quantity production demands that the elements be used in series and the present apparatus is so constructed. Within the pan 49 is a series of terminal elements, comprising elongated rectangular metal plates 57, definitely and rigidly maintained in uniformly spaced relationship by tie rods 58. The entire structure is supported in spaced relation from the bottom of the pan by suitable legs 59. A set of complementary terminal elements 60, likewise in the form of elongated rectangular metal plates, are carried by a frame 61 and are arranged to be detachably connected thereto.

In this embodiment, the frame includes a number of separable elements 62 constituting spacers, between adjacent pairs of which an edge of a plate 60 may be clamped. Such means as detachable tie rods 63 may be employed to secure the parts in assembled relation. When assembled, the plates 60 are spaced apart the same distance as the complementary plates 57 in the pan so that the plates 60 may be inserted into the bath in exact staggered relation to the plates 57, thus disposing all of the opposing terminals an exact distance apart.

The plates 57 and 60 are included in an energizing circuit and are connected to effect the deposit of resistance material on the plates 60.

Where graphite is the resistance element, the plates 60 constitute the anodes of the cell and the plates 57 the cathodes. The circuit includes a lead 64 from the cathodes 57 to the negative side of a direct current generator 65 or other suitable source of direct current, a lead 66 from the anode plates 60 to the positive side of the generator 65, a circuit making and breaking device 67 in the lead 66, and a power measuring apparatus 68 such as a voltmeter connected across the leads 64, 66.

Means is provided for lowering the frame 61 and the anode plates 60 into the electrolyte by controlled stages. Thus, the frame 61 is detachably supported in insulated relation by the upwardly extending arms 69 of a yoke member which includes a post 70 mounted on the base 52 for vertical movement. Such means as a rack 71 on the post 70 engaged by a pinion 72 on a shaft 73 may be employed for reciprocating the yoke. A lever 74 is provided for rotating the shaft 73 and a ratchet arrangement 75 provides an accurately controllable means for lowering the plates 60 into the electrolyte by stages.

In operation the anode plates are assembled upon the frame and the frame placed upon the yoke so that the anode plates may be lowered into the electrolyte with each plate 66 disposed exactly between an adjacent pair of cathode plates 57 and accurately and evenly spaced from each. Preferably, at least the anode plates are of a highly polished material and should be chemically cleaned before they are mounted in the frame to insure an even and uniform deposit of material thereon. The highly polished plates facilitate the ultimate transfer of the graphite section therefrom.

After the anode plates have been properly located with respect to the cathode plates, the operator manipulates the lever 74 to lower the anode plates into the electrolyte bath and by stages increases the depth of immersion. The immersion depth at any stage is predetermined to produce a deposition thereon of desired width and the amount of material which is deposited at any stage is controlled by the input of energy as determined by the duration of current flow. Herein the source of power from the generator 65 is constant and the circuit making and breaking device 67 is of any suitable type whereby the duration of power input can be controlled. The device may be a manually controlled one as shown or various automatic types of devices may be used.

To facilitate an understanding of the operation of the device the following electroplating schedule is used in the production of a variable tapered resistance having the specification previously set forth. The plating is done upon anode plates four inches wide:

Stage	Depth of immersion in inches	Duration of plating in sec. at 6 volts
1	$\frac{9}{16}$	25
2	$\frac{1}{4}$	8
3	$\frac{1}{4}$	5
4	$\frac{1}{4}$	2
5	$\frac{2}{4}$	1
6	$\frac{2}{4}$	1
7	$\frac{2}{4}$	1

It will be evident that as plating occurs throughout the various stages, additional coats of graphite will be deposited over those coats which were produced at a previous stage and in

addition a single coating is deposited upon the newly immersed section of the plate. When the final deposition has been performed, the lower edge portion of the plate carries a heavy coating of graphite providing a low resistance section, which coating diminishes in thickness upwardly of the plate with consequent increasing resistance to terminate in a thin, high resistance coating.

When the deposition of graphite is complete the anode plates are withdrawn from the electrolyte and, since the graphite coating is wet, there is a slight tendency of the coatings, which were applied at the various stages, to blend thus eliminating sharp "breaks" or "step-offs" of resistance along the marginal portions of the successive coatings. The plates are dried in any suitable manner to produce the graphite section shown fragmentarily in Fig. 4.

It will be seen that this manner of forming the graphite section produces a number of sections simultaneously and with absolute uniformity. As illustrated, twenty sections are produced at the same time since a section is formed on each side of each anode plate. Fig. 5 is an exaggerated illustration of this section and the graphite masses are indicated therein at 60^a. Where an untapered resistance is to be formed the anode plates are lowered to a desired depth in the bath and a proper quantity of energy applied to form a uniform deposition of graphite thereon.

In some instances it will be desirable to increase the speed of production by using double width anode plates and mounting said plates on the frame 61 with the spacers 62 engaging the central portions of the plates. The edges of the plates on one side of the frame may then be coated, the frame reversed and the edges on the other side of the frame treated, thus doubling the production. Certain types of tapered resistances may require the formation of a heavy mass of graphite along opposite edges of the anode plates separated by an intermediate thin mass of graphite. This formation may be produced by depositing graphite along one edge of the plates in the manner described, then reversing the plates on the frame by securing the coated edges thereto, and depositing graphite on the uncoated edges.

After the paper and graphite sections have been produced they are consolidated to form the completed unit and it is preferred to accomplish this end during the step of incorporating both sections with a dielectric base. It is preferred to employ as a base laminated sheets which have been impregnated with an uncured phenol condensation product and to embed the sections in the base while curing said product. To avoid non-uniformity of the resulting unit, it is necessary that the impregnation of material with the phenol condensation product be quite uniform and to this end it is preferred to use part of the mechanism shown in Fig. 1 for impregnating the material. A strip of paper or the like is passed from a roll through the bath 14 which, in this instance, comprises a suitable uncured phenol condensation product. The material is then passed through the drying chamber and the drying temperature accurately regulated since variation otherwise results. It is not necessary in this step of the process to use the recirculating flow nor the refrigerating systems. The material after it has been dried is cut into lengths suitable for handling.

The assembly of the impregnated strips, the paper section and the graphite section to form the completed unit, is preferably accomplished in the following manner, reference being had to Fig. 6. A sufficient number of strips of the impregnated paper to form a base of predetermined thickness are stacked together, as indicated at 76. A paper section 77 is placed in abutment with the outer impregnated sheet and an anode plate 60 is placed next to the paper section with the graphite section thereon facing said section. A second paper section 78 is placed against the graphite section on the other side of the plate 60 and several sheets of impregnated paper strips 79 are placed against the section 78. This assembly, or a number of such assemblies, is subjected to heat and pressure to cure the phenol condensation product, which operation transfers each graphite section from the plate to the adjacent paper section and effects an intimate combination of the graphite and paper sections. These combined sections are, in effect, embedded in the base provided by the stacks of paper strips 76 or 79. Thus, for each plate 60 two complete units are obtained. The quantity of phenol condensation product with which the base strips, and particularly the strip next adjacent to a paper section are impregnated should be predetermined by experiment so that a slight impregnation of the paper and graphite sections occurs during curing to bind the sections to the base. If too little of the product is used the graphite surface will wear, while if too much is used the graphite surface will be hard and electrical noise in the completed unit will result.

The combined strip when completed is, as shown in Figs. 7 and 8, an elongated strip comprising a dielectric base 80 presenting resistance material 81 on one surface thereof. During the combining operation, the taper of the resistance remains substantially unchanged and, consequently, is present in the completed strip. This strip may be cut or otherwise suitably formed to produce the resistance unit in its final form. In making resistance units of conventional arcuate form, as indicated at 82 in Fig. 7, the unit may be stamped or formed in a punch pressing operation. Where the resistance element is tapered, the unit is taken from a predetermined portion of the strip to produce the desired taper in the unit. By merely adjusting the rotational position at which the units are cut from the strip, it is possible to obtain units having different taper curves and resistance characteristics. In Fig. 7 the resistance units 82 and 83 are illustrative of units which are formed from different rotational positions. Or if desired, the strips may be cut into rectangular sections as indicated at 84 and then bent into substantially cylindrical shape with the exposed surface of the resistor facing either inwardly or outwardly for assembly in a resistance device of the cylindrical type.

From the foregoing it will be evident that a novel resistance unit of this type may be produced by a simple and efficient process. The units are impervious to wear, are not affected by temperature or humidity changes, the resistance characteristics remain unchanged during use and do not in operation produce electrical noise. Hence the units are especially suitable for use in radio apparatus. Moreover the present process is particularly adapted for the commercial production of resistance units in quantity since the accurate control produces uni-

formity of result within quite narrow limits of tolerance.

I claim as my invention:

1. The process of making resistance elements which includes the steps of causing adherence between particles of graphite and an absorbent sheet, drying said sheet, depositing a graphite mass on a base by electrophoresis, combining said sheet and mass into a unit by transferring said mass from said base to said sheet, and mounting the combined mass and sheet on a dielectric base.

2. The process of making resistance elements which includes the preliminary steps of (a) applying graphite particles uniformly over the surface of a sheet of material and (b) of causing an electrophoretic deposition of graphite on a supporting member, and the final steps of first placing the graphite deposit on said supporting member against said sheet in direct contact therewith, and then transferring said graphite from said supporting member to a base by imbedding both the mass of graphite on said supporting member and said sheet in a phenol condensation product impregnated base while curing said product.

3. The process of producing electrical resistance units which includes the preliminary step of forming a resistance element in several separate planar sections, at least one of said sections being formed by the electrophoretic deposition of resistance material on a supporting member, and the final steps of placing said sections of resistance material in abutment with each other and with a surface of a base impregnated with a phenol condensation product, and curing said product under heat and pressure to imbed the sections in said base and transfer the deposited material from said supporting member.

4. The process of forming resistance elements which includes the steps of immersing successive portions of an anode to increasing predetermined depths in an electrolyte containing suspended finely divided particles of graphite, and at each depth passing predetermined quantities of electrical energy through the cell in order to deposit successive layers of graphite on said anode of an area equal to the effective area of the portion of the anode immersed in said electrolyte.

5. The process of forming resistance elements which includes the steps of varying the extent to which a pole of an electrophoretic cell is inserted into an electrolyte containing a resistance material, and electrically depositing a predetermined quantity of material at each position in order to deposit successive layers of resistance material on the pole equal in area to the effective area of the pole immersed in said electrolyte.

6. The process of forming resistance units which includes the steps of successively immersing an electrode element to various predetermined depths in an electrolyte containing suspended finely divided particles of graphite, passing at each depth predetermined quantities of electrical energy to produce a known deposition of graphite on said electrode, drying said electrode, and transferring the deposited graphite from said electrode to a dielectric base containing an uncured phenol condensation product while curing said product under heat and pressure.

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