March 18, 1958 D. W. MOORE ET AL 2,827,536

METHOD OF FABRICATING FILM RESISTOR ELEMENTS

Filed Nov. 4, 1954

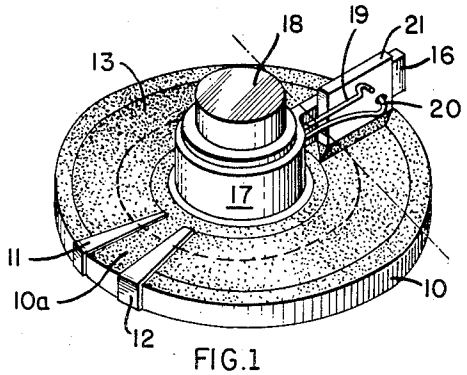


FIG.1

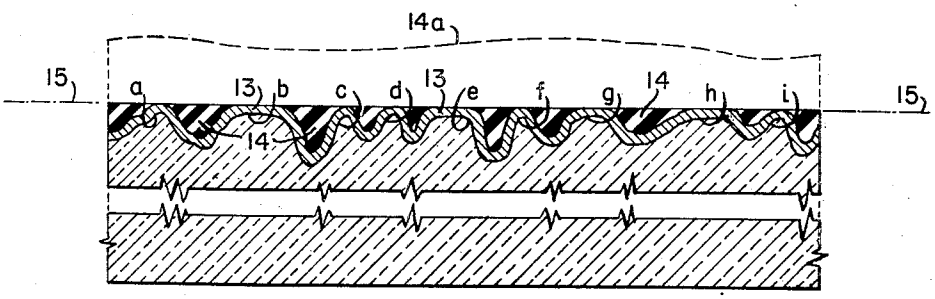


FIG.2

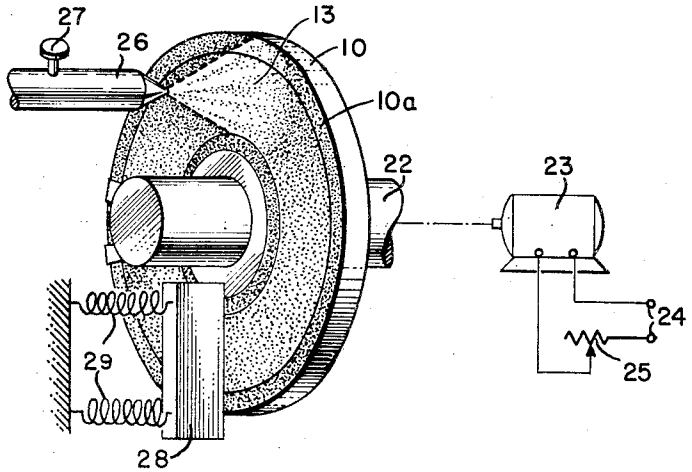


FIG.3

United States Patent Office 2,827,536 Patented Mar. 18, 1958

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METHOD OF FABRICATING FILM RESISTOR ELEMENTS

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Application November 4, 1954, Serial No. 466,806

10 Claims. (Cl. 201—55)

This invention relates to the method of fabricating film resistor elements for use in adjustable resistor devices and, more particularly, to the method of fabricating precision film resistor elements having a high degree of stability over a wide range of environmental conditions and over a long life cycle.

Film resistor elements for use in adjustable resistor devices and precision film resistor elements having a high degree of stability over a wide range of environmental conditions and over a long life cycle, such as are made under the within application, are per se the subject matter of a copending divisional application filed by David W. Moore and Ora F. Kuhlman on May 31, 1957, as application Serial No. 662,750, entitled Film Resistor Element.

Resistor elements comprising an extremely thin film of stable non-oxidizing metal thermally evaporated in a vacuum upon an insulation form, such as a glass plate, have been found useful in adjustable resistor applications requiring a precisely predetermined resistance-displacement characteristic stable over a wide range of ambient conditions and over a long life cycle. Because of the extreme thinness of such metal films, sometimes of only a few molecules thickness, a difficulty has been encountered in utilizing a contact element or brush bearing directly on the film since the wear of a film by such a contact element, while microscopic, may nevertheless be an appreciable fraction of the film thickness, thus substantially changing the resistance characteristic of the unit. To avoid such deterioration, another type of resistor element has heretofore been proposed in which such a resistance film is superposed upon a commutator structure and contact is made with portions of the commutator elements extending beyond the resistance film. Resistor elements of such construction are described and claimed in the patent of D. W. Moore, Jr., Reissue No. 23,219, and in the copending application of D. W. Moore, Jr., Serial No. 151,430, now Patent No. 2,720,572, filed March 23, 1950.

While metallic film resistor elements of the types described are reasonably satisfactory for certain applications, they are subject to a number of limitations. For example, resistor elements of the first type are usually formed on a base member of plastic or glass or other dielectric material having a comparatively smooth surface. In such resistor elements, the thickness of the film has been a compromise between that required to obtain the desired resistance per square and that adequate to withstand brush wear for a reasonable life cycle without an undue percentage resistance variation. Specifically, the required resistance per square is frequently of such a value that it can be obtained by a film of practical dimensions only by the use of an extremely thin film, while such a thin film results both in a normal brush wear giving unacceptable resistance variations over a moderate life cycle and an unacceptable resistance stability characteristic. On the other hand, the elimination of this wear by the use of separate commutator elements,

as in the second type of resistor element described, reduces the resolution obtainable and increases the cost and complexity of the unit.

It is an object of the present invention, therefore, to provide a new and improved film resistor element for use in an adjustable resistor device which obviates one or more of the above-mentioned limitations of such resistors heretofore proposed.

It is another object of the invention to provide a new and improved precision resistor element for use in an adjustable resistor device, which maintains a high degree of precision and a stable overall resistance value over a wide range of environmental conditions and over a long life cycle.

It is another object of the invention to provide a new and improved film resistor element for use in an adjustable resistor device which provides a maximum resistance per square for a film of any given thickness.

It is another object of the invention to provide a new and improved film resistor element for use in an adjustable resistor device, in which abrasion by a contact brush is negligible over a long life cycle.

It is still another object of the invention to provide a new and improved method of fabricating a film resistor element for use in an adjustable resistor device by means of which the resulting resistor element has one or more of the desirable characteristics mentioned hereinafter, e. g., one which obviates one or more of the above-mentioned limitations of the resistors hereinbefore proposed which maintains a high degree of precision and a stable overall resistance value over a wide range of environmental conditions and over a long life cycle and which provides a maximum resistance per square for a film of any given thickness, and one in which abrasion by a contact brush is negligible over a long life cycle.

In accordance with the invention, in an adjustable resistor device, there is provided a resistor element comprising an extended-surface base member of dielectric material, such surface being granular in character, and a high-resistance metallic film formed directly on and bonded to the base-member surface, the film being of a uniform thickness of a lower order of magnitude than the mean grain size of the base-member surface.

Further in accordance with the invention, the process of fabricating a resistor element for an adjustable resistor device including a base member of dielectric material comprises grinding a surface of said member to impart thereto a granular surface having a predetermined mean grain size, masking such ground surface to expose a desired portion thereof, depositing a thin high-resistance metallic film directly on such exposed surface portion, applying a protective coating of dielectric material to the deposited film, and removing excess coating to expose a multiplicity of minute areas of the film.

By the term "high-resistance film" as used herein and in the appended claims is meant a film in which the high resistance is determined primarily by the thinness of the film and secondarily by the specific resistance of the material of which the film is composed. The term "grinding" as used herein and in the appended claims is used to include conventional lapping and abrading processes.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawing, while its scope will be pointed out in the appended claims.

Referring now to the drawing:

Fig. 1 is a perspective view of an adjustable resistor device including a resistor element embodying the present invention;

Fig. 2 is a very much enlarged fragmentary cross section of the resistor element of Fig. 1; while

Fig. 3 is a schematic representation of an apparatus for performing certain of the steps of fabrication of the resistor of Fig. 1.

Referring now to Fig. 1 of the drawing, there is represented an adjustable resistor device incorporating a resistor element embodying the invention. The resistor element comprises a base member **10** of dielectric material which may be in the form of a circular disc of unglazed, homogeneous, non-porous ceramic material, such as steatite. The disc **10** has an extended substantially plane surface **10***a* which is granular in character. For example, this surface **10***a* may be ground with a grit material such as aluminum oxide or silicon carbide having a grain size within the range of 1 to 500 microns, the resistance per square varying over a wide range directly with variations in grain size. Formed on the disc **10** are a pair of conductive terminals **11**, **12** which may be formed in a known manner, for example, as described in aforesaid copending application, Serial No. 151,430, now Patent No. 2,720,572. The portion of the surface **10***a* between the terminals **11**, **12** is preferably coated or sealed with a smooth, glassy vitreous or ceramic glaze to avoid the formation of a graphite film on the rough granular surface, tending to short circuit the terminals. A high-resistance metallic film **13** is formed directly on and bonded to the surface **10***a* as described hereinafter, the film **13** being of uniform thickness of a lower order of magnitude than the mean grain size of the surface **10***a*, specifically, within a range of a few molecules to a few microns. The resistance film **13** is formed of a stable, non-corroding metal such as a noble metal, a nickel-chromium alloy, or the like.

Superposed upon the film **13** and the exposed surface **10***a* is a protective coating of dielectric material, which may be deposited as described hereinafter, leaving exposed a multiplicity of minute areas of the film. The dielectric coating material may be a self-hardening drying oil, silicone, varnish, etc., a 5% sodium silicate solution, by weight, having been found particularly suitable for this purpose. The relationship of the resistance film, the protective coating, and the surface **10***a* is shown in very much enlarged cross-sectional detail in Fig. 2. The surface **10***a* is granular or jagged in character, very irregular in configuration, as shown in Fig. 2 by the dotted-line peaks *a*, *b*, *c*, *i*, falling in a common plane. The thin metallic film **13** conforms closely to this irregular surface configuration. The thicker protective dielectric coating **14** is somewhat smoother and follows generally the configuration shown by the dotted line **14***a*. If the excess of this coating material is then uniformly removed, as described hereinafter, it is levelled off to a plane, such as that represented by the trace, **15**, **15**, including the individual peaks of the granular surface **10***a*, so that a minute area of the film **13** is just exposed through the dielectric coating **14** at each of the peaks.

Referring again to Fig. 1, the complete adjustable resistor device includes a brush arm **16** extending from a hub **17** pivoted on a shaft **18** to which the disc **10** is secured in any conventional manner. Extending from the hub **17** are a pair of strip or wire biasing springs **19** and **20** which engage a graphite brush element **21** and which respectively bias it vertically downward into engagement with the film strip **13** and against the face of the brush arm **16** to restrict movement of the brush **21** substantially to the vertical plane of the brush arm **16**. The general arrangement of the brush **21** and its brush arm **16** forms no part of the present invention, but is described and claimed in the copending application of Ora F. Kuhlman, Serial No. 466,805, now Patent No. 2,794,892, filed concurrently herewith.

In an adjustable resistor device of the type described, it will be noted that the brush element **21**, in general, contacts the microscopic exposed portions or peaks of the metallic film **13** but contacts the dielectric coating material **14** over a preponderant area of the resistor element. With this arrangement, operation of the device over a large number of cycles results in a wearing primarily of the graphite brush **21** by the dielectric coating material, rather than a wearing of the resistance film by the brush element, as in prior film resistors of this type. The wearing of the graphite brush **21** is not too important, since these brushes are inexpensive and may be readily replaced.

The resistor element described may be fabricated by any of a number of processes, but there follows a description of a preferred process. Initially, the surface **10***a* of the ceramic base **10** is ground to impart thereto a granular surface having a predetermined grain size. Specifically, one surface satisfactory for the purposes of this invention has been formed by an initial coarse grind with a grit of silicon carbide of 120 micron grain size followed by a finishing grind with a grit of aluminum oxide (Al_2O_3) of 22.5 micron grain size, imparting to the surface **10***a* a granular configuration having a grain size of the order of 20 microns. The terminals **11** and **12** may be formed by applying a conductive paint and firing, as described in aforesaid copending application, Serial No. 151,430, now Patent No. 2,720,572. The surface **10***a* between the terminals **11**, **12** is then sealed or glazed by applying by conventional screening technique a glazing mixture. Any suitable vitreous or ceramic glaze may be used, but a mixture of powdered lead borate and n-butyl phthalate in proportions to form a paste thick enough to screen has been found satisfactory. The base **10** is then fired at a suitable temperature which for the mixture specified is approximately 1050° F. The member is then thoroughly cleaned with any conventional neutral detergent to ensure that it is substantially chemically clean. The surface **10***a* is then masked to expose a desired portion thereof corresponding to the configuration of the resistance film and there is deposited on the exposed portion a thin high-resistance metallic film. This deposition may be by thermal evaporation in a high vacuum chamber, also as described in aforesaid copending application, Serial No. 151,430, now Patent No. 2,720,572.

After the formation of the resistance element as described, the protective coating of dielectric material **14** is then deposited on the film. This protective and sealing coating may be applied by apparatus such as illustrated in Fig. 3. The base member **10** is mounted on and secured to a shaft **22** which is driven by a motor **23** energized from suitable supply circuit terminals through a speed-regulating resistor **25**. The shaft **22** and the base member **10** are rotated at a moderate speed, for example, of the order of 80 R. P. M. The surface **10***a* and the resistance film **13** are then sprayed during rotation with a liquid self-hardening coating of dielectric material, for example, a 5% solution by weight of sodium silicate. This spraying may be effected by a nozzle **26** having a control valve **27**. The spray is continued for approximately one revolution of the base member **10** and thereafter shut off. Simultaneously, a graphite wiper brush **28** displaced from the nozzle **26** by approximately 180° is biased against the surface **10***a* and the resistance film **13** by means of suitable springs **29**, **29** exerting a pressure against the face of the base member **10** of approximately 50 grams. The base member **10** is then rotated several revolutions after the nozzle **26** is shut off for wiping off excess coating material during rotation of the member **10**. Dry air heated to approximately 400° F. is then blown on the surface **10***a* during approximately 15 revolutions or so following the shutting-off of the spray nozzle **26** with the wiper brush **28** in place and approximately 30 additional revolutions with the wiper brush removed. After an interval of time, which may be of the order of 15 minutes, one or more additional coatings may be applied in the same manner.

After the application of one or more sealing and protective coatings to the resistance element, as described, it is placed in a dust-proof container for a period of about 3 hours or more at room temperature to permit it to be thoroughly dried.

The coated resistance element fabricated as described, is then preferably aged by applying to the terminals **11, 12** an over-voltage for a period of several days at an elevated temperature to stabilize its resistance value. Specifically, one aging process which has been found satisfactory comprises the application of a voltage of the order of 150% of the rated voltage for a period of 5 to 20 days at a temperature of the order of 350° F. The application of this aging voltage is continued until its rate of change of resistance with time is within the desired limits of the device.

While it will be apparent that a resistor element of the type described may be formed having a wide range of resistance characteristics, there follows by way of example only the specifications of one resistor element embodying, and constructed in accordance with, the present invention:

Base member **10**: 1⅛ inches diameter, steatite ceramic material commercially available as "Alsimag 507" from the American Lava Corp.

Surface **10***a*: Ground with 22.5 micron grit of aluminum oxide (Al_2O_3)

Resistance film **13**:

Nickel-chromium-aluminum-copper alloy film commercially available as "Evanohm" from the Wilbur B. Driver Co., of the order of a fraction of a micron thick

2.53 inches mean length

0.062 inch width

Resistance:

50 ohms/square

5000 ohms, total

Coating **14**: Sodium silicate, 5% solution by weight, 40° Baumé

It will be seen that a resistor element of the type described, due to the greatly increased length of resistance path occasioned by the granular character of the surface **10***a*, has a much higher resistance per square than prior metallic film resistors. Similarly, electrical contact may be made by a brush bearing directly on the resistor film. After the element is abraded during the break-in process, as shown in Fig. 2, further movement of the brush **21** over the resistance film results primarily in a wearing of the brush element by the hard ceramic base material and an inappreciable wear of the resistance film **13**, providing a useful life upward of a million cycles. At the same time, substantially the entire surface area of the resistance film **13** is protected by the coating **14** from environmental atmospheric conditions and from oxidizing or corrosive influences with no appreciable effect upon the resistance characteristic of the element, thereby providing greatly improved resistance stability.

While there has been described what is at present considered to be the preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. The process of fabricating a resistor element for an adjustable resistor device including a base member of dielectric material which comprises: grinding a surface of said member to impart thereto a granular surface having a predetermined mean grain size; masking said ground surface to expose a desired portion thereof; depositing a thin high-resistance metallic film directly on said exposed surface portion; applying a protective coating of dielectric material to said deposited film; and removing excess coating material to expose a multiplicity of minute areas of said film.

2. The process of fabricating a resistor element for an adjustable resistor device including a base member of dielectric material which comprises: grinding a surface of said member to impart thereto a granular surface having a grain size within the rang of 1 to 500 microns; masking said ground surface to expose a desired portion thereof; depositing a thin high-resistance metallic film directly on said exposed surface portion; applying a protective coating of dielectric material to said deposited film; and removing excess coating material to expose a multiplicity of minute areas of said film.

3. The process of fabricating a resistor element for an adjustable resistor device including a base member of dielectric material which comprises: grinding a surface of said member to impart thereto a granular surface having a grain size of the order of 20 microns; masking said ground surface to expose a desired portion thereof; depositing a thin high-resistance metallic film directly on said exposed surface portion; applying a protective coating of dielectric material to said deposited film; and removing excess coating material to expose a multiplicity of minute areas of said film.

4. The process of fabricating a resistor element for an adjustable resistor device including a base member of dielectric material which comprises: grinding a surface of said member to impart thereto a granular surface having a predetermined mean grain size; masking said ground surface to expose a desired portion thereof; thermally evaporating in a vacuum a thin high-resistance metallic film directly on said exposed surface portion; applying a protective coating of dielectric material to said deposited film; and removing excess coating material to expose a multiplicity of minute areas of said film.

5. The process of fabricating a resistor element for an adjustable resistor device including a base member of dielectric material which comprises: grinding a surface of said member to impart thereto a granular surface having a predetermined mean grain size; masking said ground surface to expose a desired portion thereof; depositing a thin high-resistance metallic film directly on said exposed surface portion; applying a protective coating of dielectric material to said deposited film; removing excess coating material to expose a multiplicity of minute areas of said film; and applying a voltage across the element to stabilize its resistance value.

6. The process of fabricating a resistor element for an adjustable resistor device including a base member of dielectric material which comprises: grinding a surface of said member to impart thereto a granular surface hava predetermined mean grain size; masking said ground surface to expose a desired portion thereof; depositing a thin high-resistance metallic film directly on said exposed surface portion; applying a protective coating of dielectric material to said deposited film; removing excess coating material to expose a multiplicity of minute areas of said film; and applying a voltage of the order of 150% rated voltage across the element for a period of 3 to 20 days to stabilize its resistance value.

7. The process of fabricating a resistor element for an adjustable resistor device including a base member of dielectric material which comprises: grinding a surface of said member to impart thereto a granular surface having a predetermined mean grain size; masking said ground surface to expose a desired portion thereof; depositing a thin high-resistance metallic film directly on said exposed surface portion; applying a protective coating of dielectric material to said deposited film; removing excess coating material to expose a multiplicity of minute areas of said film; and applying a voltage across the element while maintaining it at a temperature of the order of 350° C. to stabilize its resistance value.

8. The process of fabricating a resistor element for an

adjustable resistor device including a base member of dielectric material which comprises: grinding a surface of said member to impart thereto a granular surface having a predetermined mean grain size; masking said ground surface to expose a desired portion thereof; depositing a thin high-resistance metallic film directly on said exposed surface portion; rotating the element at a moderate speed; spraying the element during rotation with a liquid self-hardening protective coating of dielectric material; removing excess coating material to expose a mutliplicity of minute areas of said film; and curing the coating material.

9. The process of fabricating a resistor element for an adjustable resistor device including a base member of dielectric material which comprises: grinding a surface of said member to impart thereto a granular surface having a predetermined mean grain size; masking said ground surface to expose a desired portion thereof; depositing a thin high-resistance metallic film directly on said exposed surface portion; rotating the element at a moderate speed; spraying the element during rotation with a liquid self-hardening protective coating of dielectric material; wiping off excess coating material during rotation of the element to expose a multiplicity of minute areas of said film; repeating the coating process one or more times; and curing the coating material.

10. The process of fabricating a resistor element for an adjustable resistor device including a base member of dielectric material which comprises: grinding a surface of said member to impart thereto a granular surface having a predetermined mean grain size; masking said ground surface to expose a desired portion thereof; depositing a thin high-resistance metallic film directly on said exposed surface portion; rotating the element at a moderate speed; spraying the element during rotation with a liquid self-hardening protective coating of dielectric material; removing excess coating material to expose a multiplicity of minute areas of said film; and drying the coating and curing the same at an elevated temperature.

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