AUTOMATIC CONTROL SYSTEM FOR PRECISION RESISTOR MANUFACTURE

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This invention pertains to control systems and more particularly to a novel apparatus for measuring the resistance and controlling automatically the deposition of an electrical resistive coating upon a support for insulating material.

In the manufacture of fixed and adjustable resistors, the resistive material is usually applied as a thin film upon a supporting base of insulating material by a combination of various methods including printing, vaporizing, cathode sputtering, and the like. The vacuum vaporization technique, while presenting many advantages from the standpoint of electrical precision and noble qualities in the resistive material, involves difficulty in that ordinarily the achieved resistance of the deposit can only be determined by interrupting the deposition, and usually removing the element from the vacuum chamber. Even where arrangements are provided for continuously monitoring the resistance, it is difficult to interrupt the vaporization process at precisely the right instant to yield the desired ultimate resistance in the finished deposit.

It is accordingly a principal object of the present invention to provide a novel electronic system which will automatically discontinue the deposition process when the desired resistance value has been attained. As a subsidiary feature, this same electronic apparatus permits allowance for the fact that discontinuance of vaporization may not occur until a short period after the vaporizing circuit has been opened. Thus, allowance may be made for the tendency of the coating apparatus to overrun slightly when its control circuits are broken.

Another object of the invention is to provide apparatus of this type in which allowance may readily be made for the fact that the deposited resistance as measured under deposition conditions will not ordinarily be equal to the value of said resistance after removal from the vacuum chamber; for example, due to the considerable change in temperature between these two conditions.

It is another object of this invention to provide an apparatus for controlling the total deposition of conductive or resistive coatings applied to an insulating backing by thermal vaporization or like methods.

Still another object of this invention is to provide a novel electronic system for automatically measuring the electrical resistance of a coating being applied on an insulating support, without interrupting the deposition process.

Another object of this invention is to provide an electronic system for automatically controlling the deposition of a resistive film upon an insulating support and at the same time measuring the actual resistance of the film as it is being deposited.

The use of this invention in a thermal vaporization apparatus for depositing a resistive coating upon an insulating support will automatically cut off evaporation action when the resistance film reaches a desired predetermined value. This automatic control system effectively eliminates the human error caused by slow response and inaccurate judgment by the operator of the coating apparatus, thus resulting in increased production and greater accuracy of the product.

The above and other objects and advantages of this invention will be more clearly understood from the following specification, taken in connection with the accompanying drawings, in which:

Fig. 1 is a diagram, partly schematic, of the novel electronic control system as utilized with a thermal vaporization type coating apparatus,

Fig. 2 is an exploded perspective view of the object being coated and the control electrodes applied thereto, and

Fig. 3 is a circuit diagram of one embodiment of the control system illustrated in Fig. 1.

The novel apparatus now to be described is exemplified as used in an apparatus for fabricating rotary contact potentiometer resistance elements of small size and high precision. The methods employed, and the apparatus used for depositing the resistive coating, form no part of this invention and are described in detail in the concurrently filed U.S. Patent application of Lawrence B. Krauss, Serial No. 569,351, titled "Making Precision Film Resistors." Although this invention will be described herein in conjunction with a thermal vaporization apparatus for depositing a thin layer of resistive material upon an insulating support, it is understood that the invention can equally well be applied to other coating devices or methods where it is desired continuously or intermittently to measure the conductivity or resistivity of the coating being applied, and also automatically to control the deposition or rate of deposition of the coating being applied.

Referring to Fig. 1 of the drawings, there is illustrated a coating apparatus of the thermal vaporization type in which the novel control system comprising this invention is utilized. The coating apparatus includes a base 10, preferably metallic, which forms a support upon which an air tight bell jar 12 of glass or the like is arranged to be disposed in a well known manner, for evacuation of the bell jar by suitable vacuum pumps. Suitable vacuum gages and like accessories, well known in the vacuum deposition art may be provided. For measurement, control and manipulation of the parts within the bell jar during the coating operation, electrical leads are brought out through the base 10 by means of suitable vacuum seals.

The object to be coated, designated by the reference numeral 14, is in this example an insulating base element in the form of a ceramic or glass disc having a central aperture therein. Referring to Fig. 2 it is seen that the disc 14 has been prepared for this coating operation by the application on the upper surface thereof of two separate contact areas 15 and 17. These areas comprise a suitable conductive material such as silver; they are of negligible resistance and are connected to the underside of the disc 14 by conductive strips 19 and 21 respectively to make contact with the resistive coating to be applied to the underside of the disc. It is noted that the conductive strips 19 and 21 pass over the edge of the disc 14 to the under surface of the disc. The contact areas 15 and 17 are arcuate, covering a full circle on the upper surface of the disc except for an interruption substantially bisecting the angle between the conductive strips 19 and 21. The disc 14 having been prepared in the manner just mentioned is then placed in a mask and holder assembly comprising for example an outer annulus 23 together with an inner circular mask 24, centered and held by a connecting bar 25 fitting into a locating slot in the annulus 23. A detailed description of this type of mask and holder assembly is found in the aforementioned concurrently filed U.S. patent application of
In this example the exposure area of the under side of the disc 14 is ring shaped except for a small angular area under bar 25. The disc 14, held in the mask assembly just described, is positioned with this unexposed area facing downwardly upon a support 16 (Figure 1) having an opening to permit the vaporized coating material to condense upon the under face of the disc 14 and thus form the resistive coating in the desired arcuate pattern.

The material to be evaporated upon the disc 14 is deposited in a crucible 18 preferably of a high melting material such as tungsten, which can be heated by an electric current passed through the crucible along bars 20 which also support the crucible. At least one bar 20 must be insulated if the base 10 is a conductor. The current leads for heating the crucible are shown at 22 and 24, and are passed through the base 10 by suitable seals to preserve the vacuum.

To provide for the more or less continuous supply of small quantities of the basic mixture of the coating materials to the crucible 18 in the proper proportions to yield the desired composition in the finished coating, a small hopper 26 feeds the coating composition into an inclined tube 30 whose lower end is positioned substantially centrally of the crucible 18 and a short distance above it. The hopper 26 is carried by a bracket upon the framework of an electrical vibrato 32 (an ordinary double ended coil) which may be used for this purpose. Each turn may be supported by any suitable means from the base plate 10. The electrical vibration 32 is energized by an electrical circuit through leads 34 and 36 extending through the base plate 10 by suitable vacuum seals. The voltage of the circuit for heating the crucible 18, and the voltage of the circuit for energizing the vibrator 32 may each be separately controlled in a manner disclosed below. Thus the temperature of crucible 18 may be controlled, as well as the action of the vibrator 32 to produce more or less agitation of the hopper 26 to exert control over the rate at which coating material is fed into the crucible 18.

To exercise close control over the coating operation it is necessary that resistance measurements, either continuously or intermittently, be made of the coating as it is being applied. To accomplish these measurements there is provided an electrode structure 38 supported in a suitable manner within the bell jar 12. To facilitate the placing and removal of the disc 14 upon its support 16, the electrode structure 38 should be supported in a manner to permit the desired movement. Such an electrode structure support is described in detail in the aforementioned and currently filed U.S. patent application by Lawrence B. Krauss. The electrode structure 38 comprises a pair of contact pins 40 insulated from each other, and so spaced that when the electrode structure is brought to bear upon the upper face of the disc 14 as shown in Fig. 1, each electrode will contact one of the two contact areas 15 and 17 (Fig. 2). The contact pins 40 are connected by leads 42 and 44 through the base 10 by suitable seals to a measurement and control system indicated generally by the reference numeral 46.

A general description of the resistance and measurement control system 46 will now be given in conjunction with the block diagram illustrated in Fig. 1. The input to the control circuit 46 is taken from the disc 14 through contact pins 40 resting upon the conductive areas 15 and 17 which in turn are connected by the conductive contact strips 19 and 21 to the under side of the disc 14 where the resistive coating is being applied. The contact pins 40 are connected at 43 and 45 by leads 42 and 44 across a condensor 48 in one leg of a conventional Wheatstone bridge circuit designated generally by the reference numeral 50. The bridge circuit 50 is supplied with current from a source 52. The resistance introduced into the bridge circuit at 43 and 45 provides one leg of the bridge circuit. An adjacent leg, designated by the reference numeral 54, is of a predetermined resistance value, and is preferably a decade resistance box which may be set to equal the desired resistance of the coating to be applied to the disc 14. Equal values of resistors are connected across the two legs of the bridge 50 in a conventional manner. The output of the bridge 50 depends on the difference in resistance between the resistive coating deposited on the disc 14 and the standard resistance placed in the leg 54 of the bridge. As the resistive film is deposited on the disc 14 this difference in resistance becomes less and less until the bridge 50 is balanced, resulting in a zero output. If deposition of the resistive coating upon the disc 14 continues after the bridge is balanced, an error signal output is obtained with a change in polarity.

The direct current output error signal from the bridge 50 is fed through lead 56 to a chopper 58 whereby it is converted into an alternating current signal. The output of chopper 58 is fed to an A.C. amplifier 60 to amplify the error signal taken from the bridge 50. The output of the amplifier is fed to the grid 62 of a gas-filled control tube 64. A conventional thyatron may be used for this purpose. The amplifier is designed so that its output will maintain a cut-off bias on the thyatron 64, preventing conduction until the bridge 50 is balanced, which condition will occur when the desired resistance value of the coating on disc 14 is reached. When the bridge 50 reaches a state of balance, the thyatron control electrode is discharged and the gas-filled control tube 64 comes to a cut-off state. When control tube 64 becomes conductive, current from the anode 66 flows to a relay 68 which causes the opening of the normally closed contacts 70 and 72 in the heating circuit of the crucible 18 fed via leads 22 and 24 from a suitable power source through an adjustable autotransformer 74. This halts any further evaporation of coating material still remaining in the crucible 18.

Actuation of relay 68 by the firing of the tube 64 also opens the normally closed contacts 76 and 78 in the circuit for energizing the hopper vibrator 32 fed via leads 34, 36 from a suitable power source through an adjustable autotransformer 80. This halts any further feed of coating material from the hopper 26 through tube 30 into the crucible 18.

Actuation of the relay 68 by the firing of control tube 64 serves to close the normally open contacts 82 and 84 in the grid circuit of thyatron 64, so that the grid 62 is connected to ground to insure conduction until the circuit is reset for the next operation.

A delay relay 86 of the slow acting variety having contacts 88 and 90 is situated in the cathode-to-ground circuit of the thyatron 64 to prevent chattering of the controlling relay 68 before the circuit is warmed up. A reset switch 92 is also provided in the grid circuit of the thyatron 64 to enable that tube to regain control of the relay 68. This switch removes the ground from grid 62 and, tube 64 being non-conducting, releases relay 68.

The following is a general description of the operation of the apparatus described above. A blank disc 14 which has been properly prepared with conductive strips 19 and 21, is positioned on the mask 23 and the two are placed upon the support 16 in the bell jar 12. The electrode structure 38 is then positioned on the disc 14 so that contacts 40 are in firm contact with the conductive areas 15 and 17. The resistive raw material in a fine mixture to be vaporized is placed within the feed hopper 26, the bell jar 12 is secured upon the base 10 and the vacuum pumps are turned on to evacuate the space within the bell jar 12. The evaporation control transformer 74 is adjusted so that the proper temperature will be attained by the crucible 18. At the same time the hopper vibrator control 80 is set to obtain the proper feed of coating material from the hopper 26 through feed tube 30 to the crucible 18 for evaporation. The resistance in the leg 54 of the Wheatstone bridge 50 is then set to a value equal to that which is de-
sired to be coated upon the disc 14. The resistance values in the other two legs of the Wheatstone bridge are set to equal values.

The reset switch 92 is now momentarily closed, and the power applied to the crucible heater, the hopper feed vibrator and the Wheatstone bridge thus placing the automatic control circuit 46 in control of the coating operation.

As the raw coating material is being initially vaporized from the crucible 18 and being deposited upon the disc 14, the Wheatstone bridge 50 is unbalanced and produces an output voltage which is converted into an alternating current signal by the chopper 58, amplified by amplifier 60 and applied as a bias to the grid 62 of the thyratron 64 to prevent firing of the tube. As evaporation continues the unbalance voltage decreases until a point is reached when the bias on the thyratron falls below the non-conduction point. When this occurs, the thyratron fires, operating relay 68 to open the vaporizer heating circuit and the hopper vibrator circuit as well, thus halting the vaporizing process. At this point the Wheatstone bridge 50 is balanced for the desired resistance on the disc 14.

A specific embodiment of the circuit generally described in Fig. 1 and which has been found to operate satisfactorily in detail is illustrated in detail in Fig. 3. In this embodiment, the control circuit contains a conventional power supply fed by a source of alternating current 100 provided with a cut-off switch 102 and fuse. A power transformer 104 connected to the alternating current source is provided with a filament supply secondary winding 106, a high voltage secondary winding 108, and a rectifier filament winding 110. A conventional full wave rectifier tube 112 as for example a 5V3, is supplied its anode power from transformer secondary winding 108, and the cathode filament thereof is supplied from the transformer secondary winding 110 in the usual manner. A conventional filter network designated 114 is included in the output of rectifier tube 112 for smoothing purposes.

Wheatstone bridge 50 is supplied necessary power for one diagonal from the transformer secondary winding 106 through a resistor 118 and rectifier 120. The resistance of the film being coated upon the disc 14 is connected by contact pins 49 into the opposite diagonal of the bridge circuit across condenser 48 in the measuring leg of the bridge. Another leg of the bridge is provided with accurate standard resistance 54 of the variable type (such as a decade box) which is capable of being set to the value of resistance equal to that desired to be coated upon the disc 14, as described above. The resistance of the two legs of the bridge are each provided with adjustable decade resistances 136, 138 having a common control 142 so that each of these legs will have the same value of resistance when varied. The purpose in providing adjustment of these legs is to set the bridge for best sensitivity having regard to the desired resistance of the deposit, e.g., whether in a low, medium or high range. Five range positions are shown, serving from 0 to 10 ohm to 0 to 1,000,000 ohm ranges.

The output of the bridge 50 is fed through the connection 56 to chopper 58 to convert the direct current error voltage to an alternating current signal. The chopper may be any conventional type, e.g., one employing the commercially available #243 Steven-Arnold chopper. A transformer 148 connected directly across the main power source 160 supplies the necessary power for operation of the chopper. A phase-control potentiometer 146 is incorporated into the chopper coil circuit to insure the proper relationship, i.e., the output of the chopper and the anode voltage supply of the thyratron control tube 64.

The output of the chopper 58 is led through a condenser 150 to the control grid 152 of the first tube 154 of the two stage amplifier 60. Bias for the control grid 152 is obtained in the usual manner by means of grid leak resistor 156. Conventional pentode tubes, as for example, type 6577 may be utilized for the first stage of the amplifier. The two stage amplifier is of the conventional resistance coupled type well known in the art. Two rectifiers 160 and 162 which may be of the crystal diode type are reversely connected to the output of the first amplifier tube 154; 160 from the B- supply through dropping resistor 132 and 158 from the screen filter 163 to provide limiting of the output to the second amplifier tube 164 of the amplifier when the error voltage from the Wheatstone bridge 50 is very large, as for example when the coating operation has just been initiated.

The output of the second amplifier tube 164 is coupled through condenser 166, resistors 168 and 170 to the grid 62 of the gas filled control tube 64, already described, which may be for example, the commercially available tube type 5696. The output from the second amplifier tube 164 which is fed to the grid 62 of control tube 64 acts as a cut-off bias and prevents the tube 64 from firing as long as an error or unbalance voltage is developed across the Wheatstone bridge 50, as amplified by the two stage amplifier. The output from the anode of control tube 64 is connected to the winding of control relay 68 having two sets of normally closed contacts and one set of normally open contacts as already described. As explained in connection with the arrangement in Figure 1, the normally closed contacts complete the circuits to the crucible heater, and to the coating feed hopper vibrator (not shown in Fig. 3). The normally open contacts, when closed, control the control tube grid 62 to ground. A reset switch 92 is provided in the control tube grid to ground circuit to enable the grid 62 to gain control over the relay 68.

In the operation of this circuit, the standard adjustable resistance 54 is set to the value which it is desired to obtain upon the disc 14. The two resistances 138 and 136 are set to the desired range value by the common control 142, and the contacts 40 are placed properly upon the disc 14 which is to be coated with a film of resistive material. The power switch 102 is turned on, and the reset switch 92 is closed. The chamber being evacuated, and before any coating material is applied to the disc 14, a very large unbalance or error voltage is developed across the Wheatstone bridge 50. As the coating is applied to the disc 14 and the resistance of the deposit increases, the error voltage will decrease. This error voltage is converted into an alternating current signal by the chopper 58. The alternating current signal is amplified by the two stage amplifier 60 and applied as a bias to the grid of the control tube 64, to prevent firing of that tube. Control tube 64 remains in a cut-off or non-conductive state until the error voltage across the Wheatstone bridge is reduced to zero or changes polarity.

At zero error voltage across the bridge (which is reached when the resistance value of the coating on disc 14 is of the proper value), the voltage appearing on the grid of the control tube 64 permits the control tube to fire and actuate the relay 68. Actuation of the relay opens the vaporizer heating circuit, the feed hopper vibrator circuit, and connects the control tube grid circuit to ground. Note that tube 64 is self-restoring to the cut off condition because its anode is supplied with A.C. over lead 172.

To prevent chattering of the control relay 178 when the entire circuit is being warmed up for use, a slow acting relay 86 is placed in the cathode circuit of control tube 64 in a conventional manner.

The circuit illustrated in Fig. 3 and described in detail above, has been used with excellent success in controlling coating devices of the thermal vaporization type utilized in manufacturing precision precision resistors, contact potentiometer resistance elements. In tests made with the control system described herein, it was possible to achieve an accuracy of better than .01% in seventy five percent of the resistors manufactured. The accuracy
obtained by this control system as well as the sensitivity and the time constant desired, depends in great measure upon the values of the resistances utilized in the Wheatstone bridge. The time constant of the system illustrated in Fig. 3 is roughly 0.1 second, that is, the circuit will react and follow changes which take place in a minimum of 0.1 second. This time constant has been found to be satisfactory for most purposes, but may be varied, by the use of proper circuit components to any practical necessary value.

As has been indicated above, while the measurement of attained resistance in the manner indicated provides accurate information as to the progress of the deposition procedure, at least two factors prevent the direct use of this measured resistance for controlling the cut-off point of the procedure. One factor is the tendency for vaporization or deposition to continue for a small but appreciable interval after the heater circuit is de-energized; this is due in part to the thermal mass of the crucible and other parts, and the presence of kinetic molecules in the region between the crucible and the resistor itself. For a given material and conditions, it is possible to correct for this "over-run" by terminating the heater energization and/or material feed a short time prior to perfect balance of the Wheatstone bridge. To this end, an adjustable voltage divider 116 in the amplifier 60 may have its adjustable contact connected to the control grid of the tube. The setting of this adjustable contact is readily arrived at after a little experience in the production of a particular precision resistor from particular materials, so that when the control relay 68 is energized, the normal over-run will carry the deposit very close to the desired ultimate value.

The second major factor influencing the accuracy of the final resistance is the fact that the temperature of the resistive film during deposition is usually much higher than that at which the resistance element will be used. This correction can readily be made by artificially setting the comparison or standard resistance in the Wheatstone bridge to a value slightly different from the ultimate resistance desired in the finished product. If the temperature at deposition, and the thermal coefficient of resistivity are known, the setting of the comparison standard can readily be calculated; here again, experiment with a sample under actual production conditions will also enable the operator to set the comparison resistance properly. In addition, this correction may be used to compensate for the known change in ultimate resistance which will be produced by any ageing or stabilization procedure which is to be applied to the resistor element after removal from the coating apparatus.

What is claimed is:

1. In a coating apparatus, a supply of resistive coating material, thermal vaporizing means, means for feeding small quantities of coating material to said thermal vaporizing means, means for supporting a dielectric member having a pair of spaced conductive terminals fixed thereto, for exposure to the vaporized resistive material, means for measuring the electrical resistance of the coating between said terminals as it is being applied to said member, and means controlled by said measuring means to discontinue operation of said thermal vaporizer and said feed means when the electrical resistance of the coating on said member reaches a predetermined value.

2. In an apparatus for coating a dielectric member with resistively resistive material, means for continuously applying the coating material on a predetermined area of the member, means for making electrical contact with the ends of the coating as it is being applied to said dielectric member, a Wheatstone bridge resistance measuring circuit, one leg of said bridge including the resistance of the coating between said contact means, another leg of said bridge including a resistance of the value desired in said coating, control means connected to the output of said bridge, said means being in a normally inactive state when said bridge is unbalanced, and said control means being activated upon balance of said bridge to discontinue the application of the resistive material.

3. In a coating apparatus, means for continuously applying electrical resistance material to a dielectric article along a predetermined length thereof, a Wheatstone bridge, one leg of said bridge including a resistance having a value equal to the resistance desired on the article being coated, means electrically connecting the ends of the coating on the article to another leg of said bridge, whereby said bridge becomes balanced when the resistance value of said coating becomes equal to the resistance value in said first leg of the bridge, coating control means connected to the output of said bridge to operate said coating control means to terminate the coating action when said bridge reaches a state of balance.

4. In a control system for a coating apparatus having means for applying an electrical resistance coating upon an article of insulating material along a predetermined length thereof, a Wheatstone bridge, one leg of said bridge including an electrical resistance having a value equal to the desired resistance value of the article being coated, means to electrically connect another leg of said bridge to the resistive coating being applied to the article, means to amplify the output of said bridge, control means connected to said amplifying means and normally in an inoperative condition when said bridge is unbalanced, and means to place said control means in an operative condition to terminate the coating action when said bridge is balanced.

5. In a control system for a coating apparatus having means for applying a coating of electrical resistance material upon an article along a predetermined length thereof, a Wheatstone bridge, one leg of said bridge including an electrical resistance having a value equal to that desired to be coated upon the article, means for introducing to another leg of said bridge the resistance of the article as it is being coated, means to automatically balance said bridge when a desired resistance value of the coating is reached, control means for said apparatus connected to the output of said bridge, said control means including a gas switching tube normally in a cut-off condition, and means to place said tube in a conductive condition to terminate the coating operation when said bridge is balanced.

6. In a control system for a coating apparatus having means for applying a coating of electrical resistance material upon an article of insulating material along a predetermined length thereof, a Wheatstone bridge, one leg of said bridge containing a resistance of the same value that is desired to be coated upon the article, means for electrically connecting to another leg of said bridge the resistance of the article being coated, means connected to the output of said bridge to convert any unbalance into an alternating current signal, means to amplify said signal, control means connected to the output of said amplifier, said control means including an electron tube normally biased to cut-off when said bridge is unbalanced, and means including said bridge connected to remove said bias when the bridge is balanced whereby said electron tube becomes conductive to terminate the coating action.

7. In a control system for a coating apparatus having means for applying an electrical resistance coating upon an article of insulating material along a predetermined length thereof, an electrical resistance having a predetermined value, means for electrically comparing said resistance to the resistance value of the coating being applied to the article, means to amplify the difference between said values, control means connected to said comparing means and normally in an inoperative condition when said resistances are unequal, means to place said
control means in an operative condition when said coating attains a resistance equal to said predetermined resistance, and means under the control of said control means for terminating the coating operation.

8. In a control system for a coating apparatus having means for applying an electrical resistance coating upon an article of insulating material along a predetermined length thereof, a Wheatstone bridge, one leg of said bridge including an electrical resistance having a value equal to the desired resistance value of an article being coated, means to electrically connect another leg of said bridge to the resistive coating being applied to the article, means to amplify the output of said bridge, control means connected to said amplifying means and normally in an inoperative condition when said bridge is unbalanced, means to place said control means in an operative condition when said bridge is balanced, means for adjusting the operating point of said control means with reference to the balance point of said bridge, and means under the control of said control means for terminating the coating operation.

9. A process for the production of a resistor having a predetermined value, comprising applying a coating of electrical resistance material to a dielectric member between two spaced terminals thereon, gradually increasing the thickness of the coating by continuously applying additional such material thereto, continuously measuring the resistance of the resulting coating between the terminals during the coating operation, and terminating the further application of resistive coating material when a predetermined value of resistance is reached.

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