March 20, 1951 P. GODLEY, 2ND 2,545,576

AUTOMATIC CONTROL OF EVAPORATED METAL FILM THICKNESS

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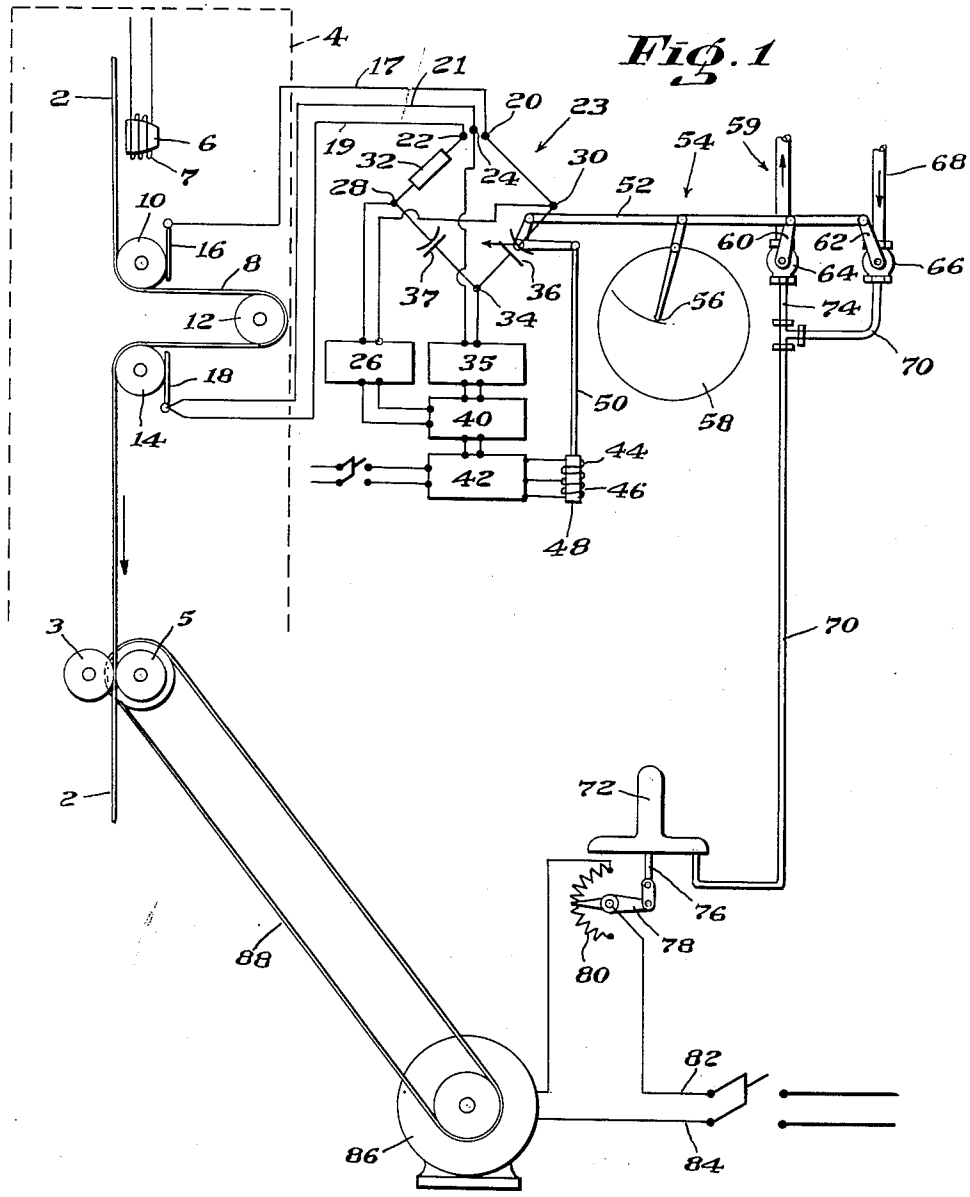



Fig. 1

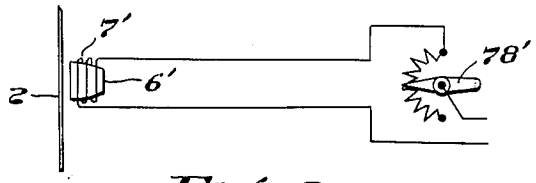



Fig. 2

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## AUTOMATIC CONTROL OF EVAPORATED METAL FILM THICKNESS

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The present invention relates to the coating of sheet material with metal and more particularly to an apparatus and method for the application of a thin continuous metal film to a dielectric sheet material in a continuous operation.

The coating process herein concerned is one in which the sheet material to be coated is passed continuously through a low pressure chamber or zone in which a coating metal is vaporized, the vaporized metal depositing on the material to form the coating. In such process it has been found impossible to provide uniform conditions of metal vaporization and deposition, with the result that the thickness of the coating varies substantially at different parts of the sheet even though a uniform rate of travel of the sheet through the coating zone is maintained. For many purposes, as in the production of metal coated paper for electrical condensers, the variations of coating thickness thus encountered are intolerable.

The object of this invention is to provide a method and apparatus by which the thickness of such a coating may be automatically regulated and maintained substantially uniform, despite repeated fluctuations in the conditions affecting the metal vaporization and deposition upon the backing material.

In practicing the invention, a sheet of dielectric material to be coated is passed continuously through a coating zone in a vacuum system, the pressure of which is maintained for example below about 1 mm. of mercury. In the coating zone the material is exposed to vapor of the coating metal which may be supplied by melting and continuously vaporizing the coating metal in the system. In such a coating process, the metal coating deposited on the surface of the sheet material is extremely thin, e. g. of the order of 0.1 micron.

I have found that variations in the electric conductivity of different unit lengths of such coating furnish an accurate and effective measure of differences in their thickness. The present invention utilizes this fact to effect an accurate control of film thickness by passing the web as it leaves the coating zone in association with a source of electric potential so that the potential is continuously impressed across a predetermined unit length of the coating on the traveling material. Variations in the resistance of the metal film to current flow resulting from variation in the thickness of the coating are automatically translated into compensating changes in the relationship between the rate at which metal vapor

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is supplied to the coating zone and the speed of the web, preferably by variation of rate of feed of the material through the coating zone, so that tendencies of the coating deposit to increase or decrease due to fluctuations in the metal vaporization or deposition conditions are promptly offset by corresponding increases or decreases in the rate of feed of the backing material. In consequence, the thickness of the coating film is maintained uniform, within much smaller tolerance limits than has heretofore been possible.

In the accompanying drawing

Fig. 1 is a schematic diagram of one form of apparatus embodying the invention; and,

Fig. 2 is a similar schematic diagram showing a modification.

Referring to Fig. 1 of the drawing, the sheet dielectric material to be coated, for example a thin regenerated cellulose film in the form of a web 2 is passed continuously through a hermetically sealed chamber partially indicated by the dotted line 4 wherein it is provided with a thin metal film. The pressure within the chamber 4 is maintained at a low value, of the order of less than 1 mm. of mercury, and the sheet material is exposed within the chamber to vapors of the coating metal. In the illustrated embodiment the coating metal, typically zinc, is contained in a crucible 6 which is continuously heated by an electrical resistance 7 to maintain the zinc at a temperature above its boiling point under the pressure prevailing within the chamber 4. As indicated above, the thickness of the metal film deposited on the web 2 may be subject to variation due to uncontrollable changes in the conditions affecting the vaporization and deposition of the metal. Such changes in thickness even when quantitatively small, are of great significance because of the extreme thinness of the film, so that even very slight differences in thickness will exceed the limits permitted in coated material to be used for many purposes, as for the manufacture of electrical condensers.

The web 2 is advanced through the coating zone by any suitable drive mechanism such as a pair of feed rolls 3, 5.

The coated web is so arranged that the electrical resistance of a fixed area of the metal film contiguous to the coating zone can be continuously measured. For this purpose the web 2 is formed into a loop 8 by passing it around a series of rollers 10, 12 and 14 as shown. The rolls 10, 12, and 14 are electrically insulated from each other and from ground. Rolls 10 and 14 are so disposed that the metal film on the web 2

runs in contact with them, thus establishing electrical connections at each end of the loop 8. The electrical resistance of the loop 8 is continuously measured, indicated and recorded, and the speed of the drive mechanism 3, 5 automatically and continuously regulated in accordance with the resistance of the loop 8 by mechanism now to be described.

A pair of brushes 16, 18 serve to connect the rolls 10 and 14 respectively to the points 20, 22 and 24 of a bridge circuit 23 through conductors 17, 19 and 21. A source of alternating low voltage potential 26 is connected to the points 28, 30 of the bridge whereby a potential is impressed across the metal film on loop 8. The bridge circuit 23 and its accessories to be described serve to indicate and record variations in the resistance of the film on loop 8 and to control this resistance within very small limits. Since this apparatus is of a conventional type, its construction will not be described in detail. Briefly, the bridge circuit includes a fixed resistor 32, of about the same resistance as the controlled resistance of the film on loop 8, connected between the points 22 and 28. A variable condenser 36 is included between the points 30 and 34 and a fixed condenser 37 is connected between points 28 and 34. Variations in the resistance of the metal film on loop 8 result in variations in the voltage across points 20, and 24 of the bridge. The voltage at point 34 may be changed by adjustment of condenser 36. As is well understood, the bridge circuit is so designed that the voltages at point 24 and at point 34 may be made the same by adjustment of condenser 36, under which conditions the bridge is "in balance."

Any unbalanced voltage between points 24 and 34 is amplified at 35 and is compared in phase in a balance control tube 40 with the voltage supplied at 26 to determine whether the bridge is unbalanced high or low. The output of the tube 40 consists of a direct current voltage of a polarity determined by the direction of bridge unbalance, and approximately proportional in magnitude to the degree of unbalance. This voltage is impressed on the grids of a push-pull amplifier tube 42 whose plate currents flow through the windings 44, 46 of a solenoid motor 48 which is connected by pull rod 50 to the rotor of the adjustable condenser 36. Changes in voltage reflecting a change in the resistance of the loop 8, are thus applied to adjust the variable condenser 36 in the proper direction to tend to bring the bridge into balance.

The solenoid pull rod 50 is also connected, through a link 52, to an indicating and recording mechanism indicated generally at 54. In this mechanism the pen 56 indicates and records on chart 58 a value which is proportional to the resistance of the film on loop 8. The chart 58 may be graduated in terms of thickness of the metal film.

The motion of the solenoid motor 48 is further applied to a fluid pressure regulator to regulate the fluid pressure supplied to a fluid motor 72 which controls a variable speed drive for the feed rolls 3, 5. This fluid pressure regulator may be of any conventional type capable of maintaining the fluid motor 72 at different positions required to provide the desired film thickness. The regulator 59 shown includes throttle valves 64, 66 having operating levers 60, 62 to which the motion of the solenoid motor 48 is transmitted by link 52. Fluid pressure supplied at 68 is transmitted through valve 66 and conduit 70 to the fluid motor 72. Fluid is bled from conduit 70 to atmosphere through line 74 and valve 64. Link 52 is so connected to valve operating handles 60, 62 as to move valve 66 toward closed position as valve 60 is moved toward open position, and vice versa.

The motor 72 is of the Sylphon or diaphragm type, preferably pneumatic, and serves to move an operating rod 76 in accordance with variations in the supplied fluid pressure. Operating rod 76 is connected to the adjustable arm 78 of a rheostat 80 so as to adjust the rheostat in accordance with movements of the solenoid motor 48. The rheostat 80 is connected into the D. C. supply lines 82, 84 in series with a series wound D. C. motor 86 which, through belt 88, drives the feed rolls 3, 5 which advance the web 2 through the coating chamber 4. It will be appreciated that variations in the conditions of temperature, metal vapor pressure, etc., within chamber 4 may require different speeds of feed rolls 3, 5 to provide the same standard thickness of metal coating. The fluid pressure regulator accordingly should be of a type which will maintain the setting of rheostat required by the conditions prevailing in chamber 4, when the pen 56 is at or very near the control point, i. e., the point corresponding to the desired thickness of metal film.

The valves 64 and 66 are so designed and connected to the link 52 as to maintain the flow of fluid out of conduit 74 in equilibrium with the flow of fluid into conduit 68 only when the pen 56 is at the control point. Any movement of pen 56 to either side of the control point will disturb this equilibrium to increase or decrease the pressure in conduit 70 and thus adjust the rheostat in the appropriate direction to move the pen toward the control point.

In the operation of my automatic control system, the web of dielectric material 2 is drawn by the feed rolls 3, 5 through the coating chamber 4 and is provided therein with a thin metal film deposited from the vapor released from the metal in crucible 6. The rollers 10, 12 and 14 serve continuously to segregate a constant length of the metal film and to connect this length into the control circuit for measurement and regulation of its resistance. Any variation in the average thickness of the film on the loop 8 results in unbalance of the bridge and the application of a voltage to the grids of the amplifier 42, thus causing the solenoid 48 to be operated. This applied voltage will be positive or negative depending upon the direction of unbalance of the bridge, which, in turn, depends upon whether the change in thickness of the film is an increase or decrease in thickness. The solenoid 48 responds appropriately to adjust the variable condenser 36 and simultaneously to indicate and record the change in film thickness on the chart 58. At the same time the setting of the valves 64, 66 is changed to increase or decrease the pressure in the supply line 70, whereupon the fluid motor 72 adjusts the rheostat 80 to vary the speed of the D. C. motor 86 to change the speed of the feed rolls 3, 5 as required. Any change in the thickness of the deposited metal film is thus promptly followed by a corrective change in the rate of feed of the web.

In the modification of Fig. 2, the rheostat 80', corresponding to the rheostat 80, is connected into the supply leads to the heating coil 7' for the crucible, 6' and is not connected to the web driving motor. The apparatus otherwise may be

identical with that of Fig. 1. Changes in the setting of rheostat 80' due to changes in thickness of the metal film result in corrective changes in the energy supplied to heat the crucible without change of the speed of the web, thus changing the relationship between the rate of supply of metal vapor to the coating chamber and the speed of the web to maintain the film thickness constant. The arrangement shown in Fig. 1, in which the web speed is varied, is preferred because it is more sensitive in its response to changes in the setting of the rheostat and thus more sensitive to changes in film thickness.

I claim:

1. Apparatus for applying an electrically-conductive metal film to a sheet dielectric material which comprises an enclosed chamber adapted to be maintained under a pressure below about 1 mm. of mercury, means for supplying metal vapor to the sheet material, a variable-speed drive for moving a web of said sheet material through said chamber with a surface thereof exposed to said metal vapor whereby a film of metal is deposited on said surface of a thickness inversely proportional to the speed of said web, a pair of electrical contacts within said chamber engaging the metal film on said traveling web at points spaced a constant distance apart on the surface of said metal film, a source of electrical potential connected across said contacts to cause current to flow through said constant length of film at a rate proportional to its thickness, and means for varying the speed of said variable-speed drive with variations in said current whereby to maintain the thickness of the metal film substantially uniform.

2. Apparatus for applying an electrically-conductive metal film to a sheet dielectric material which comprises an enclosed chamber adapted to be maintained under a pressure below about 1 mm. of mercury, variable means for supplying metal vapor at a predetermined rate to the sheet material, a variable-speed drive for moving a web of said sheet material through said chamber at a predetermined rate with a surface thereof exposed to said metal vapor whereby a film of metal is deposited on said surface of a thickness inversely proportional to the speed of said web, a pair of electrical contacts within said chamber engaging the metal film on said traveling web at points spaced a constant distance apart on the surface of said metal film, a source of electrical potential connected across said contacts to cause current to flow through said constant length of film at a rate proportional to its thickness, and means for varying one of said rates with variations in said current whereby to maintain the thickness of the metal film substantially uniform.



3. Apparatus for applying an electrically-conductive metal film to a sheet dielectric material which comprises an enclosed chamber adapted to be maintained under a pressure below about 1 mm. of mercury, variable means for supplying metal vapor at a predetermined rate to the sheet material, a variable-speed drive for moving a web of said sheet material through said chamber at a predetermined rate with a surface thereof exposed to said metal vapor whereby a film of metal is deposited on said surface of a thickness inversely proportional to the speed of said web, a pair of electrical contacts within said chamber engaging the metal film on said traveling web at points spaced a constant distance apart on the surface of said metal film, a source of electrical potential connected across said contacts to cause current to flow through said constant length of film at a rate proportional to its thickness, and means for varying the rate of supplying metal vapors with variations in said current whereby to maintain the thickness of the metal film substantially uniform.

4. Apparatus for applying an electrically-conductive metal film to a sheet dielectric material which comprises an enclosed chamber adapted to be maintained under a pressure below about 1 mm. of mercury, variable means for supplying metal vapor at a predetermined rate to the sheet material, a variable-speed drive for moving a web of said sheet material through said chamber at a predetermined rate with a surface thereof exposed to said metal vapor whereby a film of metal is deposited on said surface of a thickness inversely proportional to the speed of said web, a pair of electrical contacts within said chamber engaging the metal film on said traveling web at points spaced a constant distance apart on the surface of said metal film, a source of electrical potential connected across said contacts to cause current to flow through said constant length of film, a resistance measuring means for measuring resistance of said constant length of film as a function of said current and said potential, and means for varying one of said rates with variations in said measured resistance whereby to maintain the thickness of the metal film substantially uniform.

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