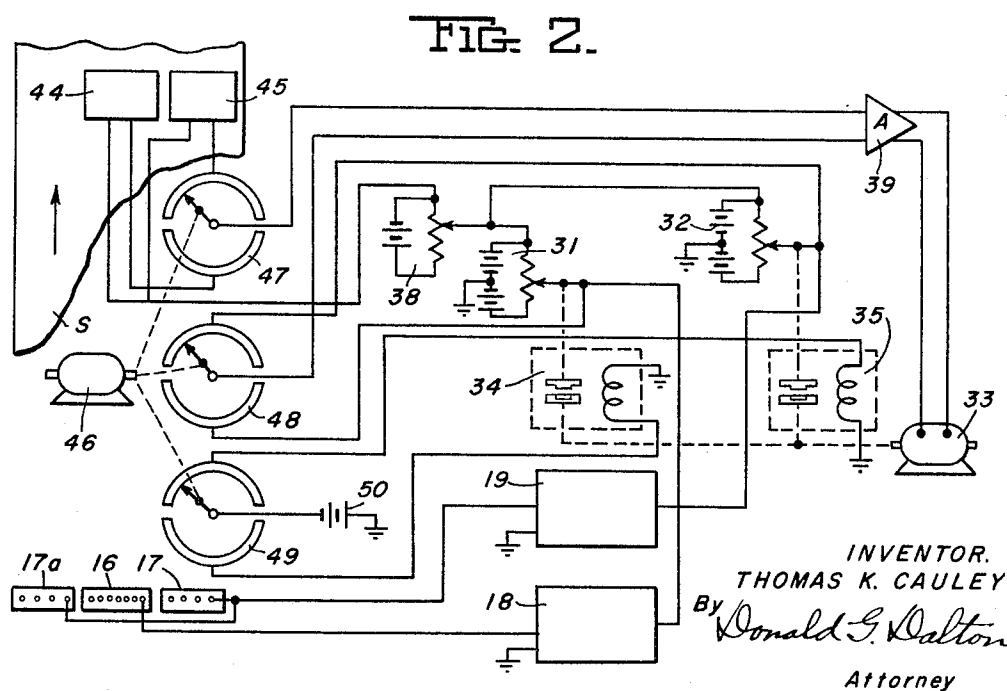
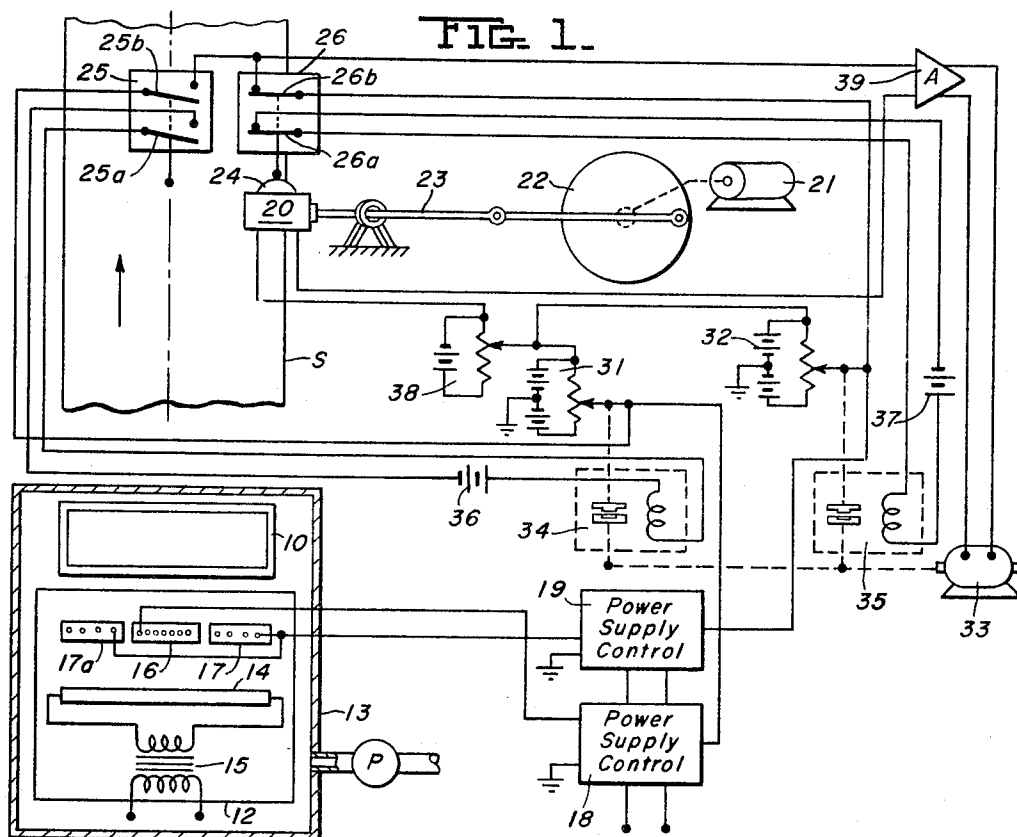


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METHOD AND APPARATUS FOR CONTROLLING COATING
THICKNESS BY ELECTRON BEAM EVAPORATION
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METHOD AND APPARATUS FOR CONTROLLING COATING THICKNESS BY ELECTRON BEAM EVAPORATION

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This invention relates to an improved method and apparatus for controlling the thickness and profile of vapor-deposited coatings.

In a conventional vapor-deposition process for coating strip material, the strip passes over a crucible which is housed in a vacuum chamber. The crucible contains coating material, which is heated to a temperature sufficient to vaporize it. The vapors condense on the strip surface and form a continuous coating thereon. Such processes can be used, for example, to coat steel strip with aluminum. Various techniques are known for heating the coating material, one of which is to direct a stream of electrons from an electron gun against the surface thereof. Reference can be made to Ruhle Patent No. 2,423,729 or Simons Patent No. 3,046,936 for showings of exemplary arrangements in which electron guns are thus used. In these processes there is a problem in controlling the coating thickness and in obtaining a coating of uniform thickness across the width of a strip. The coating tends to be thickest in the central portion of the strip, which passes over the region of the crucible where the vapors are most dense, and to thin out near each edge.

An object of my invention is to provide an improved method and apparatus, applicable to an electron-gun vapor-deposition process for coating strip material, in which the coating thickness is controlled automatically to a predetermined value.

A further object is to provide an improved method and apparatus which affords the foregoing advantage and in which the thickness is controlled individually at different locations across the width of a strip, whereby coatings of uniform thickness or of controlled variations in thickness can be obtained.

A more specific object is to provide an improved method and apparatus for controlling coating thickness in which individual grids are interposed between different portions of the cathode of an electron gun and the surface of a coating material, and the potentials on these grids are varied to regulate the intensity of the electron beam reaching different portions of the surface.

In the drawing:

FIGURE 1 is a schematic diagram of a vapor-deposition apparatus equipped with one form of control apparatus constructed in accordance with my invention; and

FIGURE 2 is a similar view showing a modification.

FIGURE 1 shows schematically a vapor-deposition apparatus which includes a crucible 10 and an electron gun 12 housed in a vacuum chamber 13. A strip S, for example of steel, travels through the chamber to be coated. The crucible is spaced a few inches below the strip path, and contains a supply of coating material, for example aluminum. The apparatus also includes conventional means (not shown) for feeding coating material to the crucible to replace what is consumed. The electron gun has a cathode 14 and a transformer 15. Both the crucible and cathode are of a length approximately equal to the strip width. The gun directs an electron beam against the surface of the coating material in the crucible and heats the surface to at least 1200 C. The coating material vaporizes and the vapors condense on the strip surface. Since the foregoing parts and their operation are conventional, no more detailed showing is

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deemed necessary. In the absence of any control, the central portion of the strip is exposed to vapor of greater density than the edge portions and hence receives a thicker coating.

In accordance with my invention, the electron gun 12 includes a grid 16 interposed between the central portion of cathode 14 and the surface of the coating material in crucible 10, and grids 17 and 17a interposed between the edge portions of the cathode and the coating material. Each grid is formed of a plurality of parallel wires which lie in a plane perpendicular to the path of electron travel. I connect grid 16 to a conventional adjustable power supply 18, and grids 17 and 17a to a separate adjustable power supply 19. One example of a suitable power supply is available commercially from NJE Corporation of Kenilworth, New Jersey, as the "Model ELA-80-50 RM" and is described in a printed publication by the manufacturer "NJE Power Suppliers, Spring 1959." The power supplies 18 and 19 transmit controlled negative potentials to the grids to retard different portions of the electron beam by different degrees. In the illustration the wires of grid 16 are spaced more closely than the wires of grids 17 and 17a, whereby at equal potentials grid 16 offers a greater electrostatic gradient than grids 17 and 17a. Consequently the edge portions of the electron beam are retarded less than the central portion and tend to vaporize greater quantities of coating material, whereby the coating thickness tends to be more nearly uniform across the strip width.

To control the coating thickness more precisely, I adjust the two power supplies 18 and 19 to vary the potentials applied to grids 16, 17 and 17a in accordance with the measured thickness of the coating on different portions of the strip S. I measure the coating thickness with a conventional X-ray thickness gage 20, which is located outside chamber 13 and produces an electric output signal proportional to the coating thickness. The technique for measuring coating thickness with an X-ray gage is known, as explained, for example, in Friedman Patent No. 2,926,257. I connect gage 20 to a mechanism which periodically shifts it back and forth between a first position where it measures the coating thickness at the central portion of the strip and a second position where it measures the coating thickness at one edge portion. As illustrated, this mechanism includes a motor 21, an eccentric 22 and a connecting rod 23. Gage 20 carries a cam 24, which closes a normally open double-pole switch 25 when the gage is over the central portion of the strip and closes a similar switch 26 when the gage is over the edge portion.

The control circuit includes two self-balancing potentiometers 31 and 32, the arms of which are electrically connected to the power supplies 18 and 19 respectively. A reversible motor 33 is mechanically connected to the arm of potentiometer 31 through a magnetic clutch 34 and to the arm of potentiometer 32 through another magnetic clutch 35. I connect one contact 25a of switch 25 in series with the winding of clutch 34 and an energizing source 36. Similarly I connect one contact 26a of switch 26 in series with the winding of clutch 35 and an energizing source 37. Thus when either switch closes, the corresponding clutch is engaged. If motor 33 runs when clutch 34 is engaged, it moves the arm of potentiometer 31 to change the control voltage transmitted to the power supply 18. The output of the power supply 18 and the potential on grid 16 change correspondingly. Likewise if the motor runs when clutch 35 is engaged, the potential on grids 17 and 17a changes.

The circuit also includes a set-point potentiometer 38 and a conventional amplifier 39. I connect the slide wire of the set-point potentiometer 38 and the output of X-ray

gage 20 in series to one input terminal of the amplifier. I connect the arm of the set-point potentiometer to the slide wire of the self-balancing potentiometer 31, and connect the arm of potentiometer 31 in series with the other contact 25b of switch 25 and the other input terminal of amplifier 39. I connect the other self-balancing potentiometer 32 and the other contact 26b of switch 26 in a similar manner. I connect the output terminals of amplifier 39 with motor 33. I arrange the connections so that the sum of the voltages from the X-ray gage 20 and the self-balancing potentiometer 31 or 32 oppose the voltage from the set-point potentiometer 38. Hence motor 33 is energized only when the opposing voltages are unequal.

In operation, I manually adjust the arm of the set-point potentiometer 38 in accordance with the thickness of coating I wish to maintain on the strip. I operate motor 21 to move the X-ray gage 29 periodically between its two positions. When the gage is in its first position overlying the central portion of the strip, both contacts 25a and 25b of switch 25 close. If the coating is not of proper thickness, the combined voltage transmitted by the X-ray gage and self-balancing potentiometer 31 differs from the voltage transmitted by the set-point potentiometer 38. Motor 33 runs in a direction to adjust potentiometer 31 to overcome this voltage difference. The adjustment of potentiometer 31 also changes the potential on grid 16 in a direction to correct the coating thickness. The gage next moves to its second position and in like manner corrects the coating thickness at the edge of the strip. The magnitude of each adjustment signal is in accordance with the measured error in coating thickness, but the gage soon moves away from its measurement position and opens the contacts of switch 25 or 26 before completion of the adjustment. I time the gage movement in relation to the strip speed so that the region of the strip on which a thickness correction has been made reaches the gage before there is another correction. In this manner I avoid hunting.

FIGURE 2 shows a modification in which I use two X-ray gages 44 and 45 and avoid continually shifting the gage. The mechanism includes a motor 46 and three double contact rotary switches 47, 48 and 49, the arms of which are mechanically connected to said motor. The remainder of the circuit is similar to that already described. Motor 46 periodically moves the arm of switch 47 to a first position in which it establishes a connection between the X-ray gage 44 and amplifier 39 and a second position in which it establishes a connection between the X-ray gage 45 and the amplifier. In like manner switch 48 establishes connections between the self-balancing potentiometers 31 and 32 and the amplifier, and switch 49 between clutches 34 and 35 and a source of energy 50.

From the foregoing description it is seen that my invention affords a simple method and apparatus for controlling the thickness of a vapor-deposited coating. Although I illustrate arrangements in which the coating thickness is measured at only two locations on the strip, it is apparent the thickness could be measured at a larger number of locations and that a larger number of grids could be used. I can also use a similar apparatus to control the profile of the coating so that different portions of the strip intentionally have coatings of different thickness.

While I have shown and described certain preferred embodiments of my invention, it is apparent that other modifications may arise. Therefore, I do not wish to be limited to the disclosure set forth but only by the scope of the appended claims.

I claim:

1. In a vapor-deposition process for applying a coating to the surface of a strip in which the strip passes over a supply of the coating material housed in a vacuum chamber, an electron beam is directed against the surface of the supply and heats the coating material to a tempera-

ture sufficient to vaporize it, and the vapors condense on the strip surface, the width of said supply and of said beam being approximately equal to the strip width, the combination therewith of a method of controlling the coating thickness comprising interposing electrostatic potentials between the source of said beam and the surface of the supply of coating material to modify the heating effect of said beam, and individually varying the degree to which the heating effect is modified in different portions of said beam across its width, thereby varying the quantity of material vaporized at different portions of said supply.

2. A method as defined in claim 1 in which said potentials are negative to retard said beam.

3. A method as defined in claim 1 in which the strip is steel and the coating material is aluminum.

4. A method as defined in claim 1 in which said beam is modified to vaporize relatively greater quantities of coating material opposite the edge portions of the strip than in the central portion to produce a coating of substantially uniform thickness.

5. In a vapor-deposition process for applying a coating to the surface of a strip in which the strip passes over a supply of the coating material housed in a vacuum chamber, an electron beam is directed against the surface of the supply and heats the coating material to a temperature sufficient to vaporize it, and the vapors condense on the strip surface, the widths of said supply and of said beam being approximately equal to the strip width, the combination therewith of a method of controlling the coating thickness comprising measuring the coating thickness at a plurality of locations across the width of the strip, interposing electrostatic potentials between the source of said beam and the surface of the supply of coating material, and individually varying the intensity of said potentials in different portions of said beam across its width in accordance with the measured thickness of the coating, thereby varying the quantity of material vaporized at different portions of the surface of said supply.

6. In a vapor-deposition apparatus for applying a coating to the surface of a strip, which apparatus includes a crucible adapted to contain a supply of coating material, an electron gun having a cathode for directing an electron beam at the surface of said supply, a vacuum chamber housing said crucible and said gun, and means for moving a strip over said crucible, the widths of said crucible and said beam being approximately equal to the strip width, the combination therewith of an apparatus for controlling the coating thickness comprising a plurality of grids interposed between said cathode and said crucible, means connected to said grids for applying electrostatic potentials thereto to modify the heating effect of said beam, and means for individually varying the degree to which the heating effect is modified at different grids across the width of said beam, thereby varying the quantity of material vaporized at different portions of said crucible.

7. A combination as defined in claim 6 in which said potentials are of negative polarity to retard said beam and produce a greater retarding effect in the central portion of said beam than at the edge portions.

8. A combination as defined in claim 7 in which each of said grids is formed of a plurality of parallel wires which lie in a plane perpendicular to the direction of travel of said beam, the wires of the grid opposite the central portion of said beam being spaced more closely than the wires of the grids opposite the edge portions.

9. In a vapor-deposition apparatus for applying a coating to the surface of a strip, which apparatus includes a crucible adapted to contain a supply of coating material, an electron gun having a cathode for directing an electron beam at the surface of said supply, a vacuum chamber housing said crucible and said gun, and means for moving a strip over said crucible, the widths of said crucible and said beam being approximately equal to the strip width, the combination therewith of an apparatus for controlling the coating thickness comprising means for measuring the

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coating thickness at a plurality of locations across the width of the strip, a plurality of grids interposed between said cathode and said crucible, individually adjustable power supplies connected with said grids for applying negative potentials thereto to retard said beam in varying degrees across its width, and an electric circuit connecting said measuring means and said power supplies to adjust said power supplies in accordance with the measured thickness of the coating to maintain the thickness in a predetermined pattern.

10. In a vapor-deposition apparatus for applying a coating to the surface of a strip, which apparatus includes a crucible adapted to contain a supply of coating material, an electron gun having a cathode for directing an electron beam at the surface of said supply, a vacuum chamber housing said crucible and said gun, and means for moving a strip over said crucible, the widths of said crucible and said beam being approximately equal to the strip width, the combination therewith of an apparatus for controlling the coating thickness comprising means for producing electric signals proportional to the coating thickness at a plurality of locations across the width of the strip, a plurality of grids interposed between said cathode and said crucible, individually adjustable power supplies connected with said grids for applying negative potentials thereto to retard said beam to a relatively greater degree in its central portion than in its edge portions, and an electric circuit connecting said signal-producing means and said power supplies to adjust said power supplies in accordance with the signals, thereby vaporizing greater quantities of coating material opposite the edge portions than opposite the central portion as required to deposit a coating of substantially uniform thickness.

11. A combination as defined in claim 10 in which said signal-producing means includes an X-ray gage

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mounted outside said chamber, and means for periodically shifting said gage between a first position in which it acts on the central portion of the strip and a second position in which it acts on one of the edge portions.

12. A combination as defined in claim 11 in which said circuit includes a set point potentiometer connected with said gage, and self-balancing potentiometers connected between said gage and the respective power supplies for making adjustments in the output of the latter when the coating thickness varies from that set on said first-named potentiometer.

13. A combination as defined in claim 10 in which said signal-producing means includes a pair of X-ray gages mounted outside said chamber, one of said gages being located to act on the central portion of the strip, the other gage being located to act on one of the edge portions.

14. A combination as defined in claim 13 in which said circuit includes a set-point potentiometer and self-balancing potentiometers connecting said gages and the respective power supplies for making adjustments in the latter when the coating thickness varies from that set on the set point potentiometer, and switch means for periodically completing current paths to each gage in turn.

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