United States Patent [19]

Erhart et al.

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[45] **Nov. 5, 1974**

[54] **SYSTEM FOR VAPOR DEPOSITION OF THIN FILMS**

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[73] Assignee: **Xerox Corporation**, Stamford, Conn.

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[21] Appl. No.: **400,593**

Related U.S. Application Data

[62] Division of Ser. No. 244,374, April 17, 1972, abandoned.

[52] **U.S. Cl.** **118/49.1**

[51] **Int. Cl.** **C23c 13/08**

[58] **Field of Search** 118/48–49.5, 118/319–321, 53; 117/107.1; 269/57

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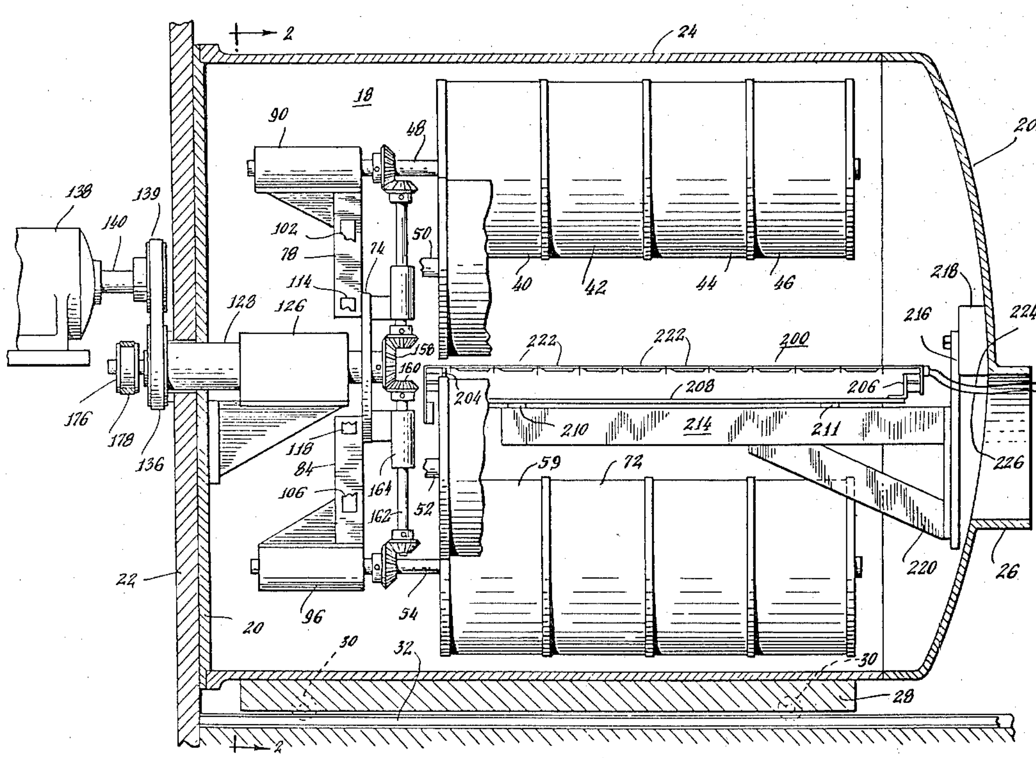
Primary Examiner—Morris Kaplan

[57] **ABSTRACT**

A method and apparatus is disclosed for vapor depositing a thin film of material on image retention surface substrate bodies comprising the steps of positioning a plurality of substrate bodies on a plurality of elongated, horizontally extending support mandrels, rotating each of said mandrels about an associated longitudinal axis thereof while simultaneously transporting said plurality of mandrels in an annular path about a horizontal axis, establishing an evacuated atmosphere about said assembly of mandrels, and vaporizing a material which is positioned in a planar array of crucibles located within a path defined by the annular travel of said mandrels.

3 Claims, 13 Drawing Figures



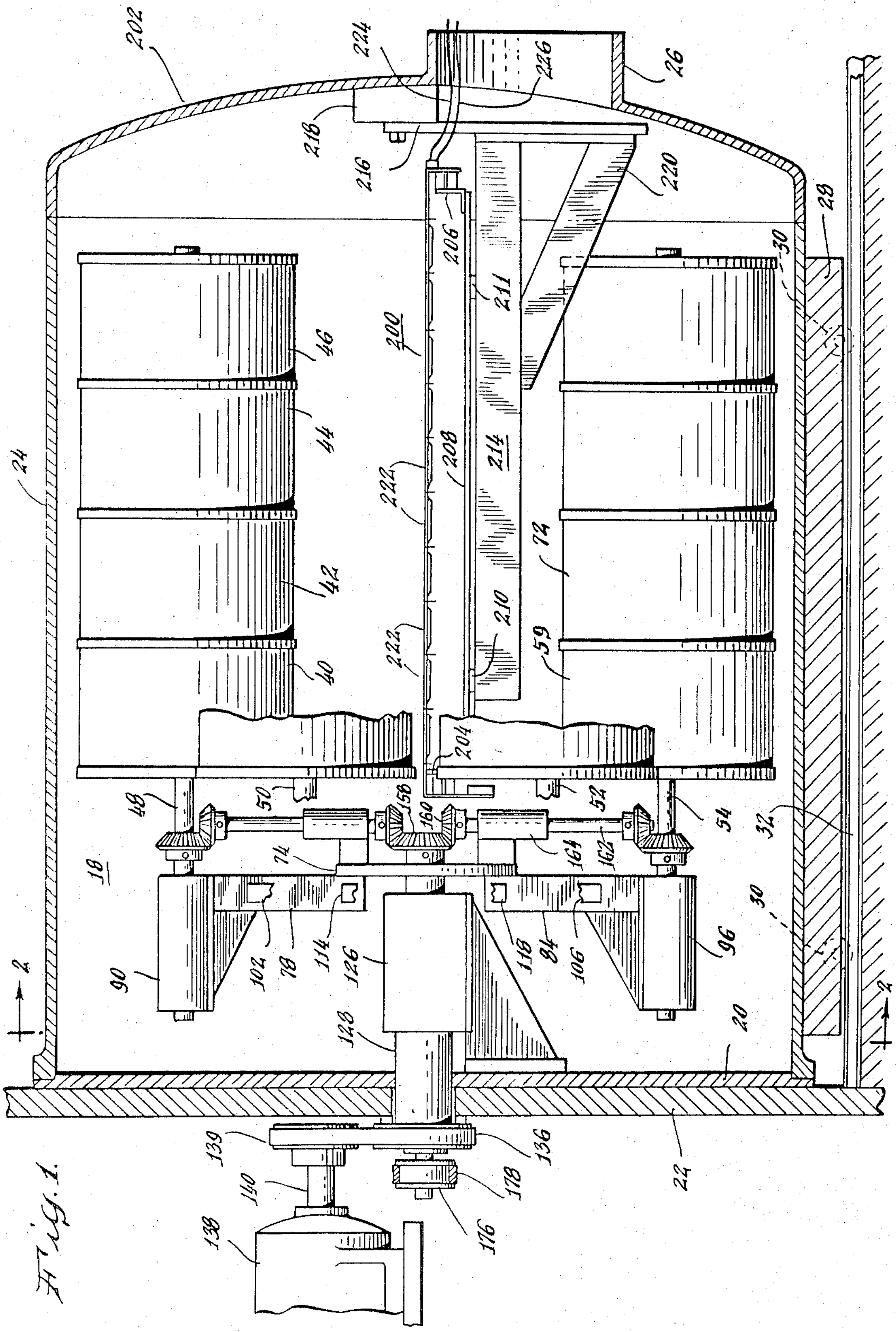

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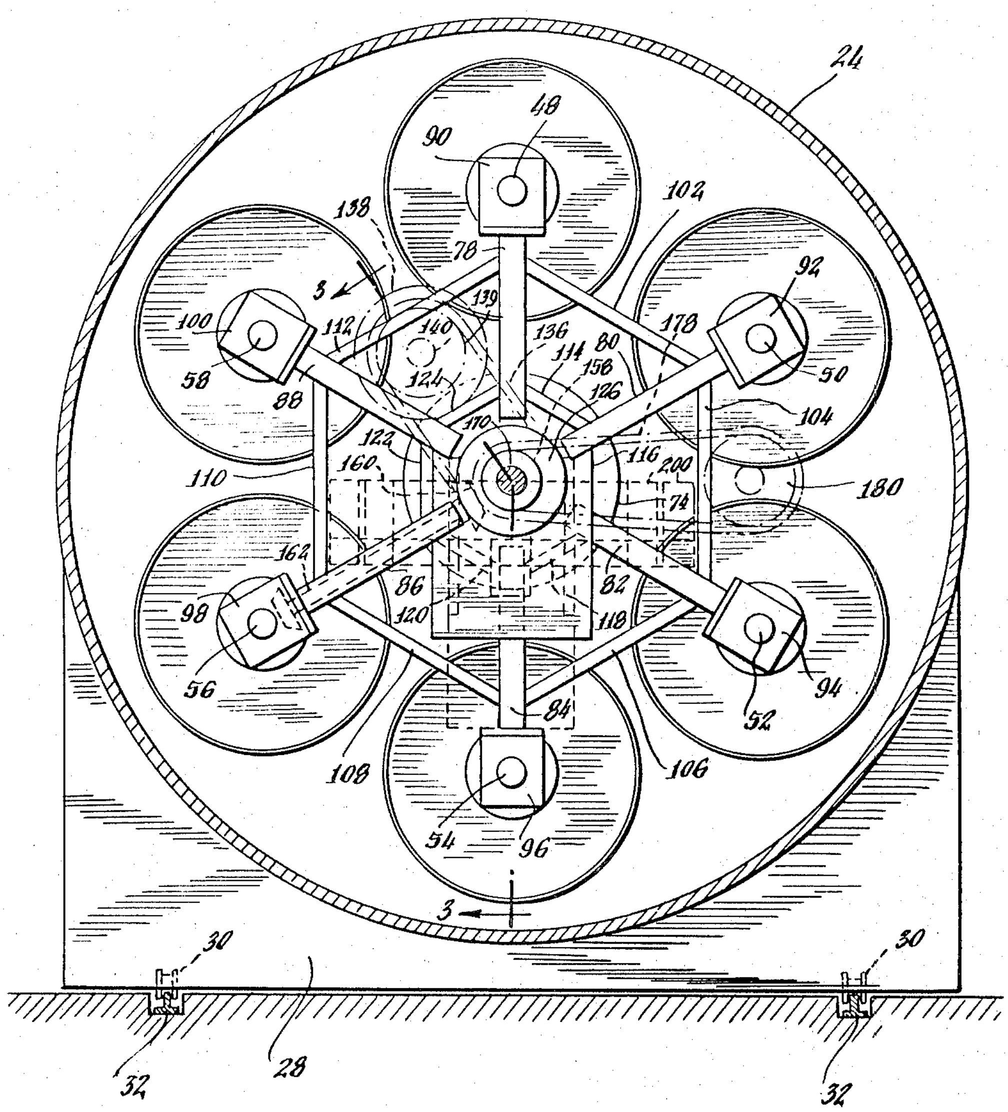
Fig. 1.

Fig. 2.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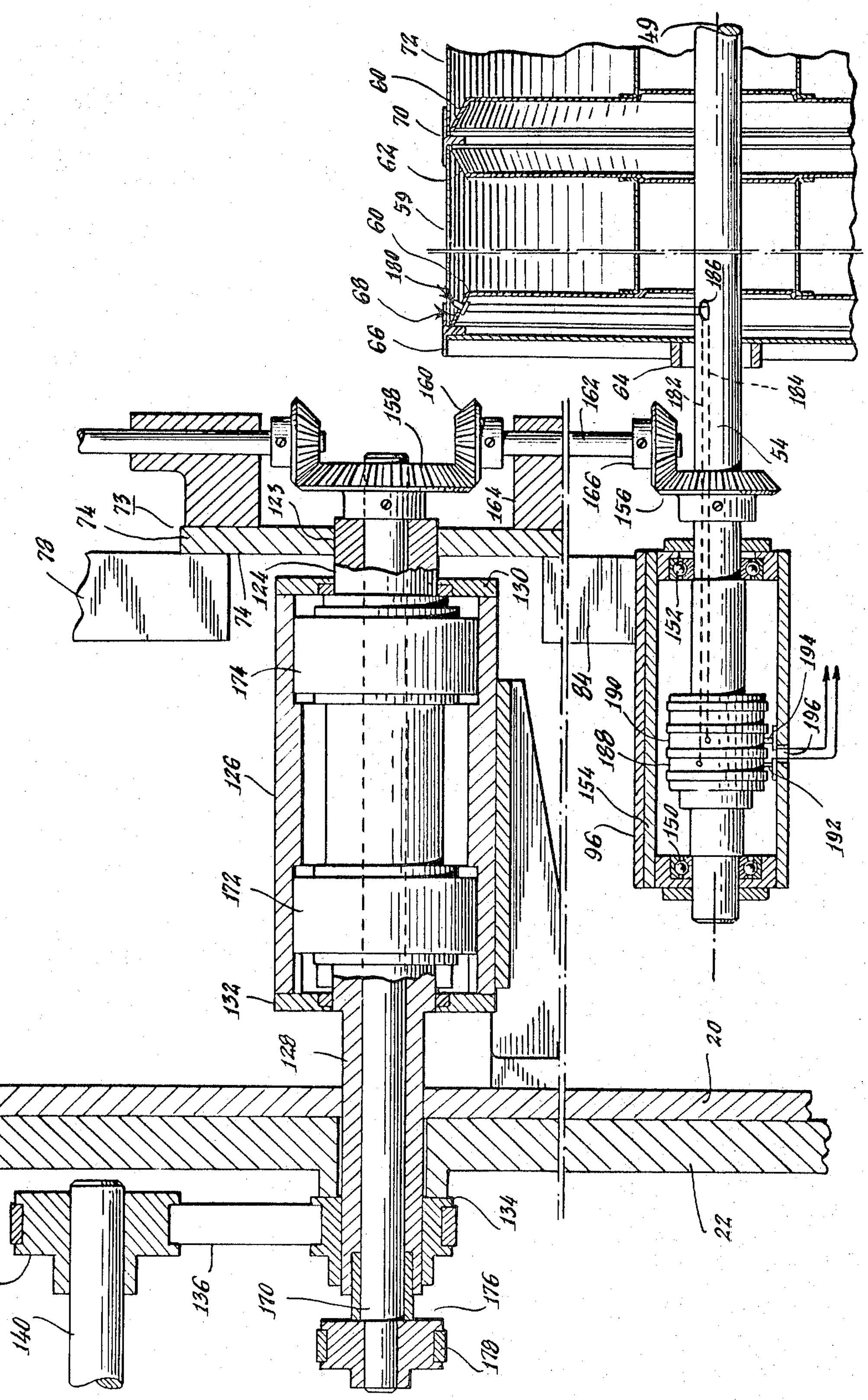

Fig. 3

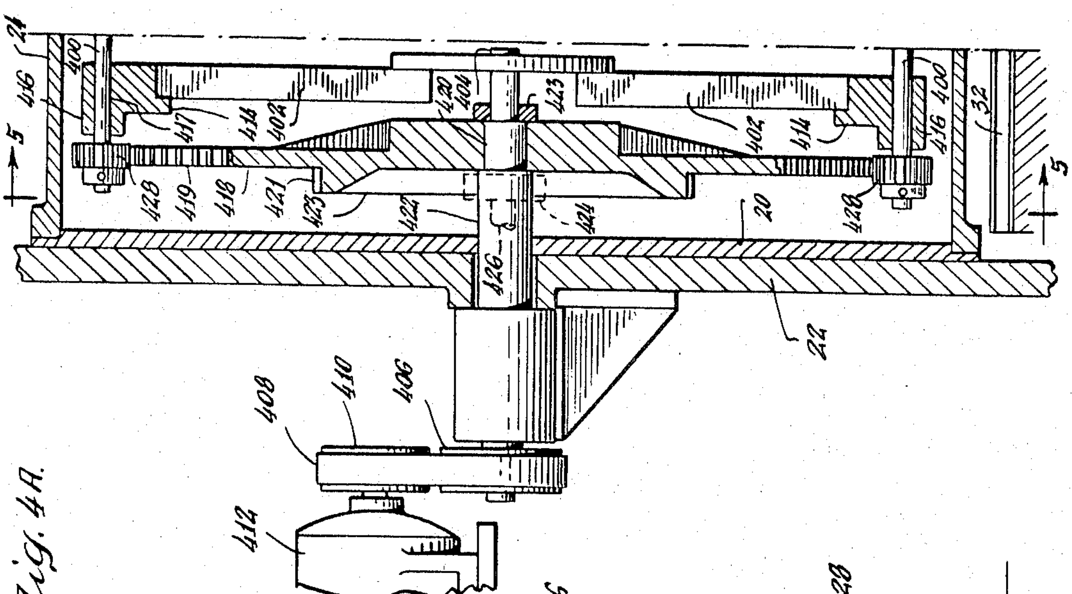
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Fig. 4A.

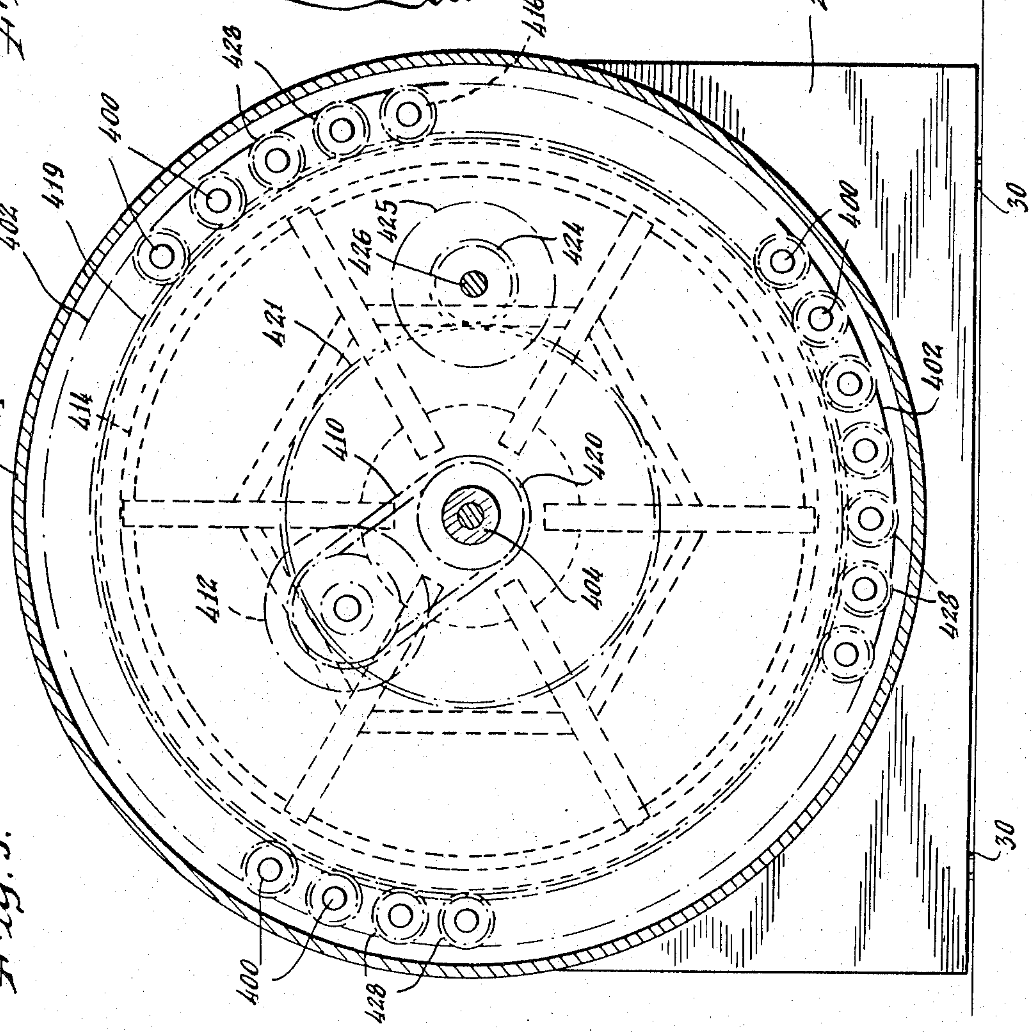
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Fig. 5.

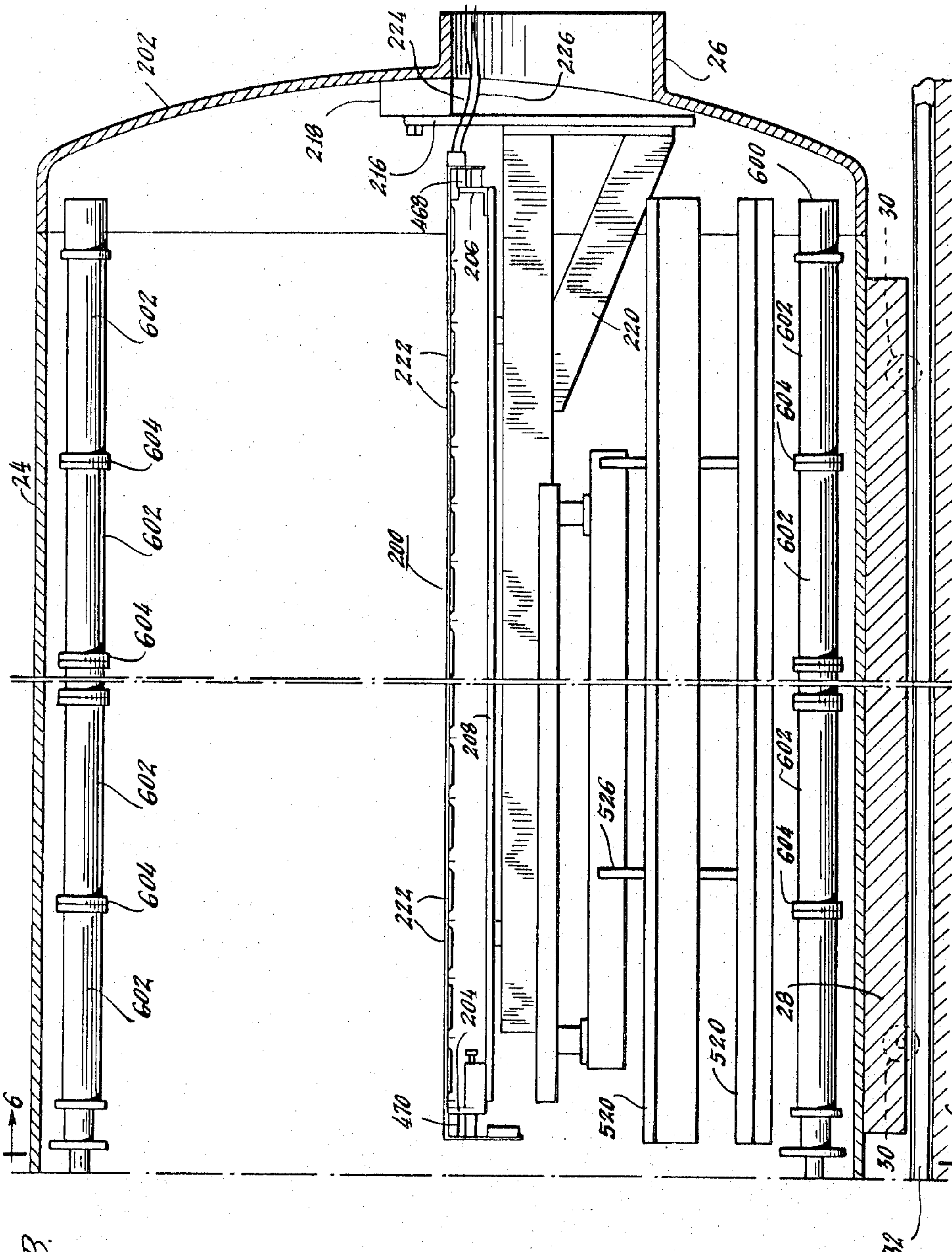
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Fig. 4B.

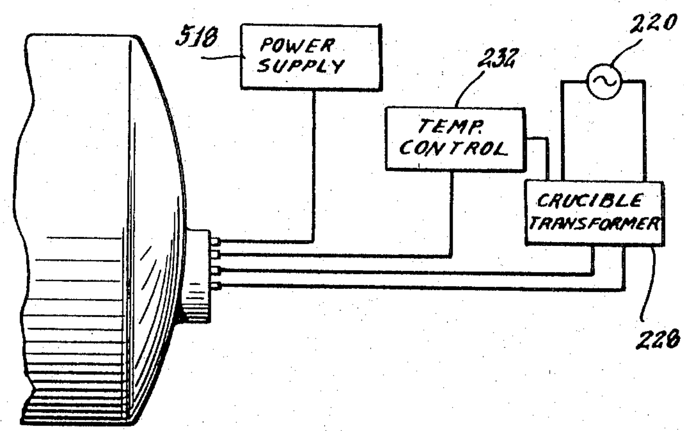
518
POWER SUPPLY
232
TEMP. CONTROL
220
CRUCIBLE TRANSFORMER
228

Fig. 10.

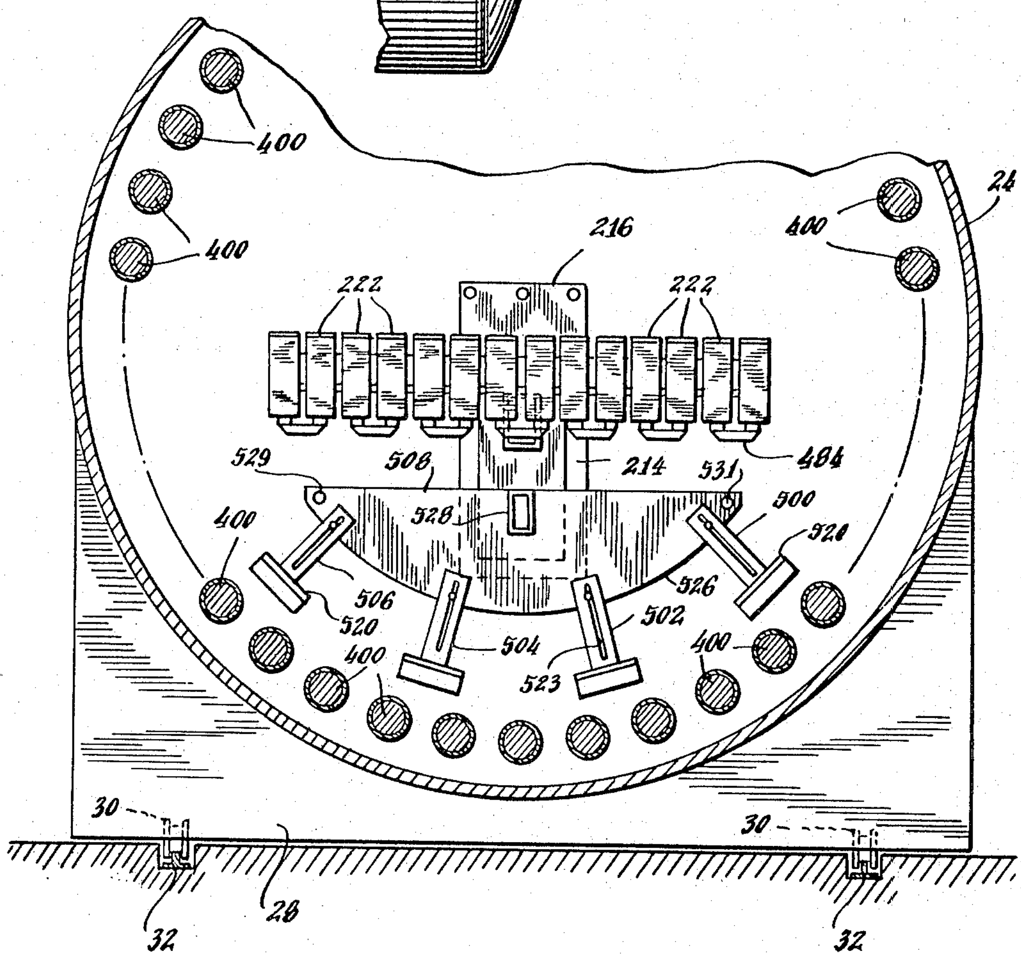
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Fig. 6.

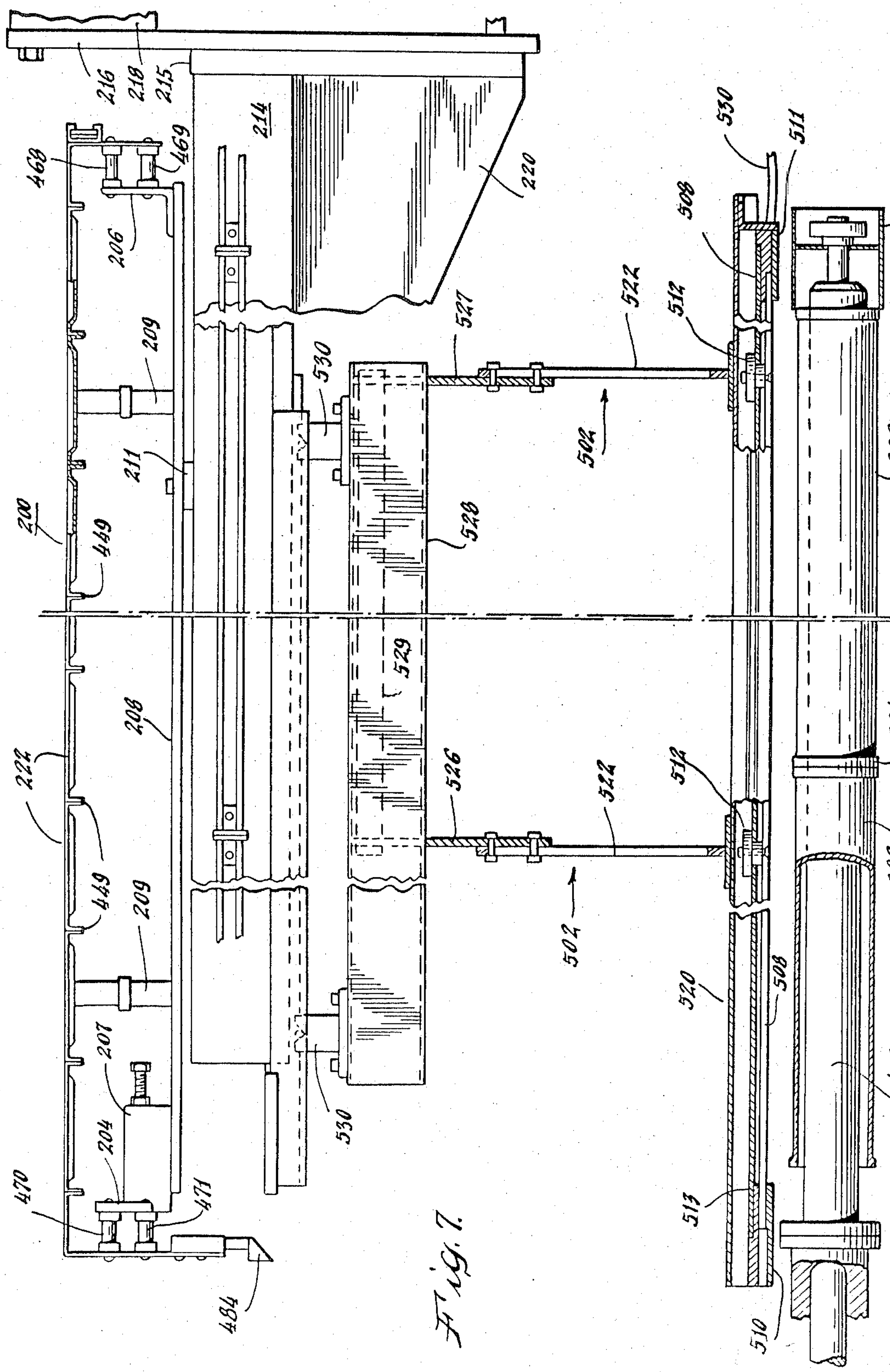
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Fig. 7

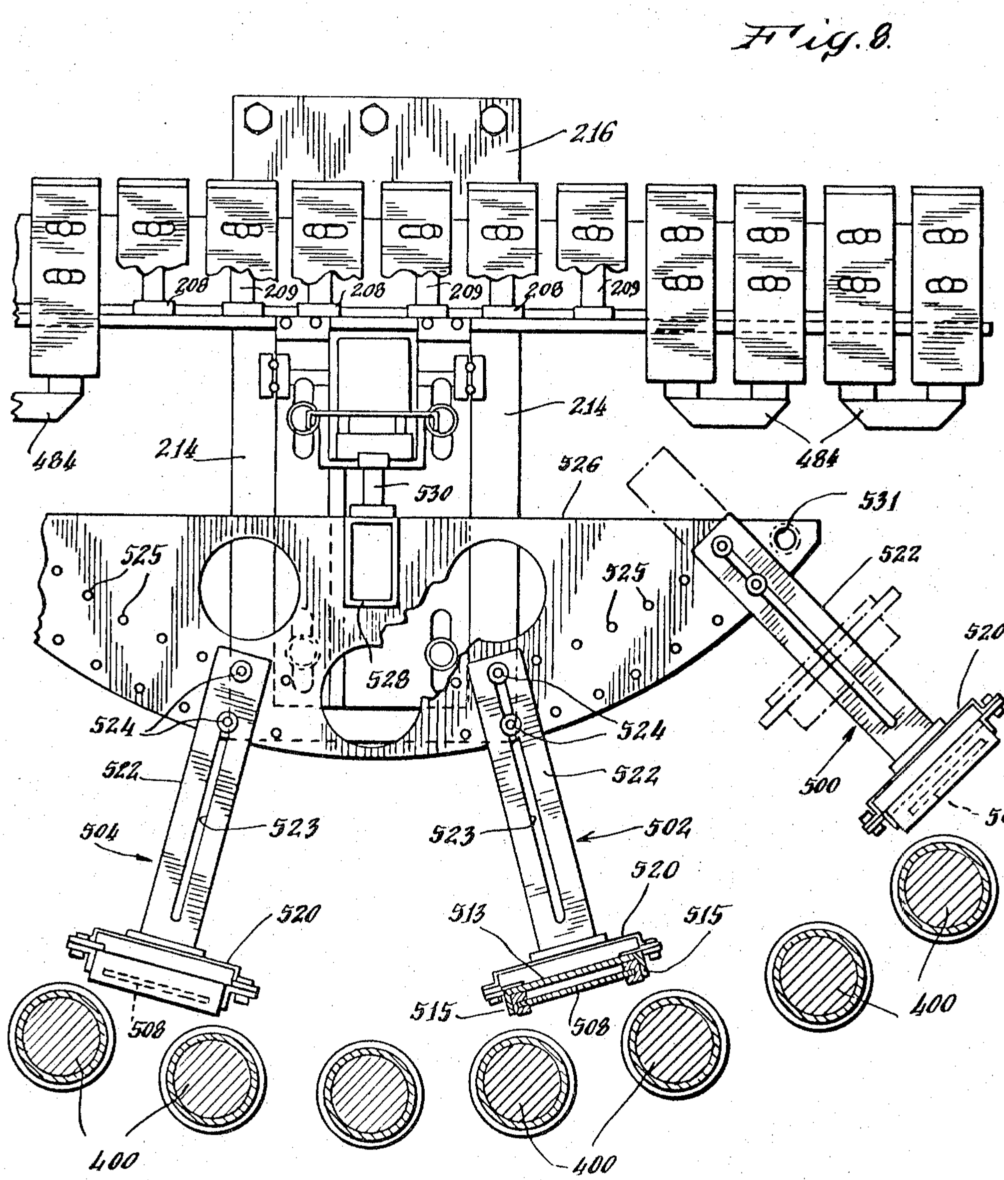
Fig. 8.
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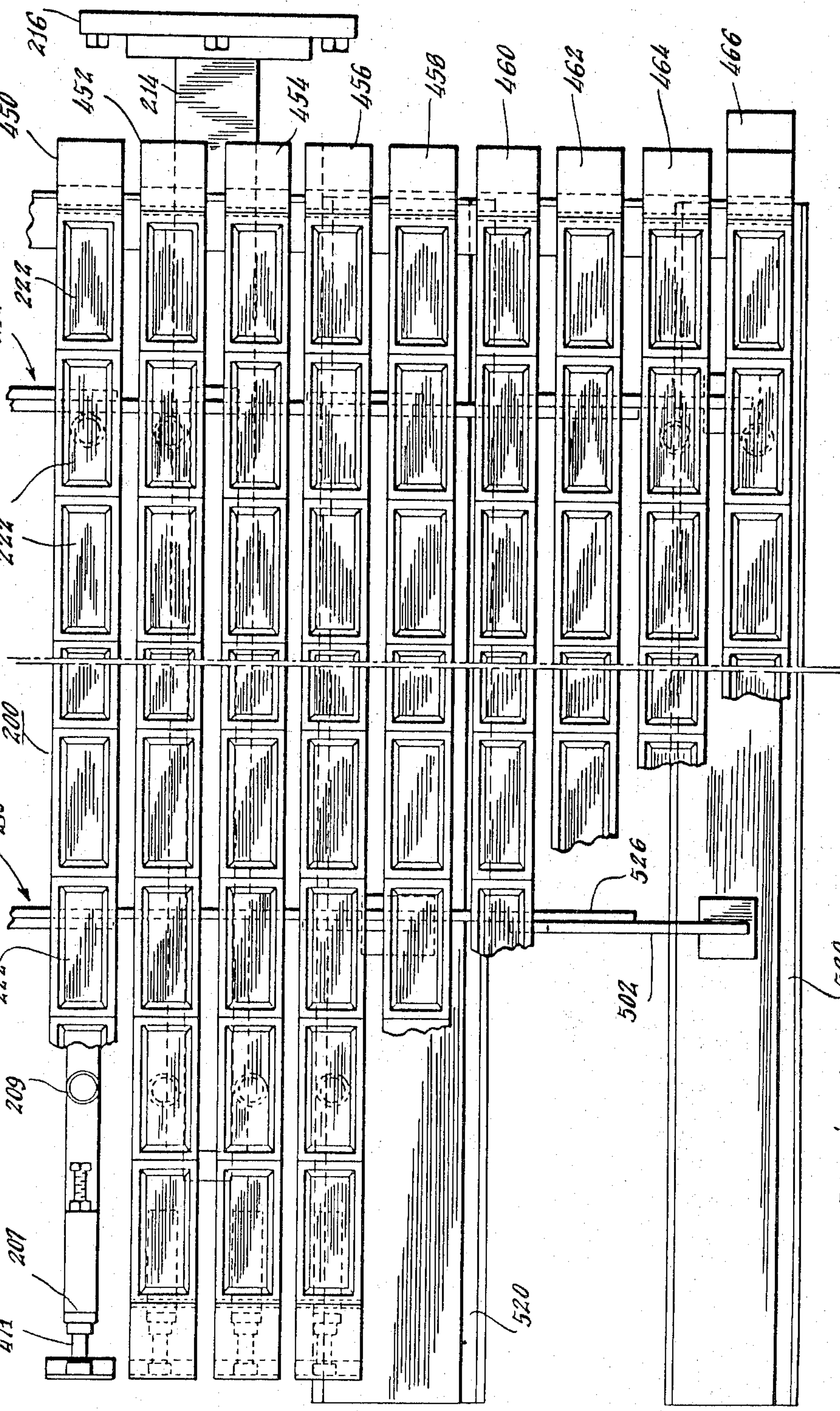
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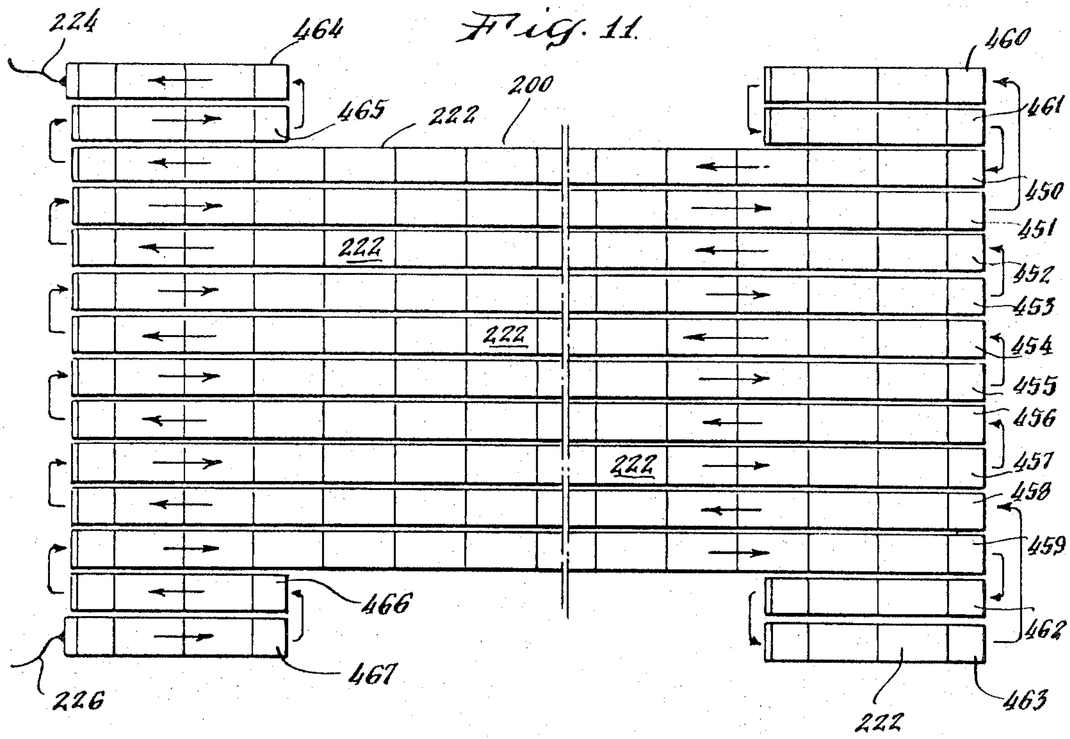
Fig. 9

Fig. 11.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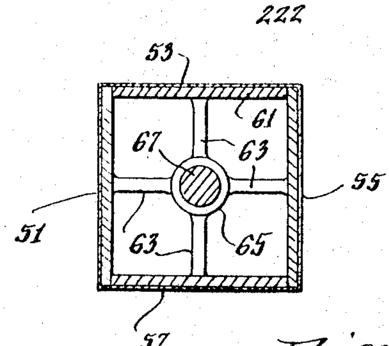
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Fig. 12.

SYSTEM FOR VAPOR DEPOSITION OF THIN FILMS

This is a continuation, division of application Ser. No. 244,374, filed April 17, 1972, now abandoned.

This invention relates to an improved apparatus for the vapor deposition of a relatively thin film on a substrate body. The invention relates more particularly to an improved apparatus for fabricating an electrostatographic plate by the vapor deposition of a photoconductive material on a substrate body.

In one form of electrostatographic reproduction system, a latent electrostatic image is formed on an image retention surface and is developed by contacting the surface with a developer material which generally comprises a pigmented, electroscopic, thermoplastic resin. Attractive electrostatic forces cause the developer material to adhere to the latent electrostatic image in image configuration. The latent image is subsequently transferred to a record medium such as a sheet or web of paper to which it is fixed.

An image retention surface in this type of electrostatographic reproduction system generally comprises a relatively thin film of photoconductor material such as selenium or alloys thereof which is deposited on an electrically conductive, substrate body. The film preferably has a thickness of about 55 to 60 microns. The substrate body is fabricatd of a metal which is formed as a drum or alternatively as a flexible endless belt. Generally, an interface is formed on the substrate body prior to deposition of the photoconductor material on the substrate body. The interface which is formed on the electrically conductive substrate body functions to provide an electrically resistive barrier between the photoconductor layer and the substrate. During image reproduction, a uniform electrostatographic charge is initially formed on the photoconductor surface. The surface is then exposed to activating electromagnetic radiation in image configuration such as is provided by exposure to a light source through a phototransparency. The photoconductor material automatically alters the charge on its surface in those areas which have been exposed to activating electromagnetic radiation.

The quality of a reproduced image in an electrostatographic reproduction system of this type is dependent in part on the characteristics of the deposited photoconductor film. This film should be substantially uniform in thickness and should exhibit uniform photoelectrical characteristics across its surface. Additionally, in order to provide uniformity of image reproduction in different electrostatographic machines, these film characteristics should be substantially uniform over all such image retention surfaces.

A photoconductor film has heretofore been formed on an electrically conductive substrate body by the vaporization and deposition of the photoconductor material on the substrate in an evacuated atmosphere. The substrate body is initially cleaned and is then surface treated or coated to establish the interface barrier thereon. Interface surface treatment is accomplished by coating or alternatively by heating the body when the body is formed of materials such as aluminum. The vaporization, deposition, and adherence of the photoconductor material to the substrate is best effected when the substrate body is brought to an elevated temperature. This process has been practiced in the past by supporting a substrate on an elongated mandrel and by rotating the mandrel about an axis thereof which extends in a horizontal plane. Heating of the substrate body was accomplished by conveying a heated liquid to the mandrel or alternatively by establishing a glow discharge between an electrode and the substrate body. The mandrel is positioned adjacent an open crucible which extends coextensively with the length of the mandrel and contains a photoconductor material. This arrangement, while operative to produce useful image retention surfaces, is limited in that the image retention surfaces thus produced exhibit variations in the characteristics of the deposited film which in great part relate to the characteristics of the associated crucible. Furthermore, these techniques do not readily lend themselves to a relatively economic and high rate of production.

Accordingly, it is an object of this invention to provide an improved method and apparatus for vapor depositing a relatively thin film of photoconductor material on a substrate body.

Another object of the invention is to provide an improved method and apparatus for producing an electrostatographic image retention surface in a relatively economic manner and at a relatively high rate of production.

Another object of the invention is to provide an improved method and apparatus for producing an electrostatographic image retention surface by vapor deposition in an evacuated chamber and which eliminates the need for a preliminary formation of an interface surface on the substrate body.

Another object of the invention is to provide an improved method and apparatus for the production of an electrostatographic image retention surface which effects relatively efficient use of the photoconductor material.

Another object of the invention is to provide an improved method and apparatus for producing electrostatographic image retention surfaces which exhibit an improved uniformity in the thickness of the deposited film.

Another object of the invention is to provide an improved method and apparatus for producing electrostatographic image retention surfaces which exhibit improved uniformity in the electrical characteristics of a deposited film.

In accordance with features of the method of this invention, a plurality of elongated horizontally orientated mandrels each supporting thereon a plurality of substrate bodies are each rotated about a horizontally orientated longitudinal axis thereof and are transported in a vertically orientated path about a planar array of crucibles containing photoconductor material. The photoconductor material is heated to a temperature for providing vaporization and deposition of the material upon the substrate bodies.

In accordance with another feature of this invention, an electric discharge is established between an electrode and the substrate bodies for forming an interface on said bodies and for preheating said bodies to a desired temperature suitable for vapor deposition.

In accordance with other features of this invention, an apparatus for depositing a relatively thin film on a substrate body comprises a vacuum chamber, a vertically orientated mandrel support plate which is rotatably mounted about a horizontal axis, a plurality of elongated, horizontal extending, rotatably mounted mandrels arrayed on the mandrel support body and rotated therewith about a planar array of crucibles. Means are provided for rotating the mandrel support body about its horizontal axis while simultaneously rotating each of the mandrels about a longitudinal axis of the mandrel. The mandrels are each adapted for receiving and supporting a plurality of substrate bodies upon which a photoreceptor film is to be vapor deposited. In accordance with other features of the apparatus of this invention, the vacuum chamber comprises a vertically positioned wall member and a bell shaped member adapted to be transported into union with the wall member and to form a vacuum tight enclosure therewith. The bell shaped vacuum member encloses the rotatable mandrel support body and the mandrels mounted thereon. The planar array of crucibles are supported fron an inner wall surface of the bell shaped vacuum chamber member and are positioned within a path of travel defined by rotation of the mandrels.

With the apparatus of this invention, electrostatographic image retention surfaces are produced at relatively high rates and in a relatively economic manner with improved physical and electrical characteristics. Additionally, the processing of the substrate body is enhanced and an improved interface is established by simultaneously heating and forming the interface immediately prior to vapor deposition.

These and other objects and features of the invention will become apparent with reference to the following specification and to the drawings wherein:

FIG. **1** is a side elevation view of an apparatus constructed in accordance with features of this invention for the vapor deposition of a thin film on a substrate body;

FIG. **2** is a view taken along lines **2—2** of FIG. **1**;

FIG. **3** is a view taken along lines **3—3** of FIG. **2**;

FIGS. **4A** and **4B** are side elevation views of portions of an alternative embodiment of an apparatus constructed in accordance with features of this invention for the vapor deposition of a thin film on a substrate body;

FIG. **5** is a view taken along lines **5—5** of FIG. **4A**;

FIG. **6** is a view, partly broken away, taken along lines **6—6** of FIG. **4B**;

FIG. **7** is an enlarged side view, partly broken away, of a portion of the apparatus of FIG. **4B**;

FIG. **8** is an enlarged view, partly broken away, of a portion of the apparatus of FIG. **6**;

FIG. **9** is a plan view of a planar array of crucibles employed with the apparatus of this invention;

FIG. **10** is a view of a portion of the vacuum chamber employed with the apparatus of FIGS. **1** and **4** and illustrating a crucible power supplying means, a glow discharge power supplying means, a glow discharge power supply means and temperature sensing and control equipment for the apparatus;

FIG. **11** is a plan view of the crucible array of FIG. **9** illustrating the flow paths of crucible heating current therein; and,

FIG. **12** is a cross-sectional view of an arrangement for vapor depositing a film on a planar substrate body.

Referring now to the drawings, and more particularly to the embodiment of the apparatus of this invention shown in FIGS. **1, 2** and **3**, there is illustrated a vacuum chamber **18** having a vertically orientated wall member **20** which is secured in a stationary position by welding, for example, to a vertical beam or wall body **22**. The chamber enclosure further includes a generally bell-shaped housing **24** having a vacuum flange member **26** mounted thereto. Electrical operating power is derived from the sources **220, 232** and **518** (FIG. **10**) and is coupled through this flange to various components within the vacuum chamber. The vacuum chamber formed by the bell shaped member **24** and the vertically orientated wall member **20** comprises a relatively large size chamber adapted for the mass production of image retention surfaces. The chamber typically has dimensions on the order of about 6 to 8 feet in diameter and 10 to 20 feet in length. It is constructed in accordance with conventional vacuum techniques for reducing the pressure within the chamber to values on the order of about 1×10^{-3} to 1×10^{-5} Torr. A pumping means, not illustrated, for pumping down the chamber to these levels comprises a conventional vacuum system which includes a roughing pump, diffusion pumps and mechanical blowers.

A plurality of electrostatographic image retention surface substrate bodies are positioned within the chamber **18** for vapor deposition of a photoconductor on the surfaces thereof. As indicated in greater detail hereinafter, these substrate bodies are supported on rotatable mandrels within the chamber. In order to facilitate the placement and the mounting of the substrate bodies within the chamber and in order to enhance the removal of these bodies subsequent to film deposition, the bell shaped vacuum chamber member **24** is adapted to be withdrawn from union with the wall member **20** for a distance sufficient for mounting and demounting of the substrate bodies on the mandrels. The bell shaped member **24** is formed, for example, of relatively heavy metal plate. In order to render it transportable in a longitudinal direction, the chamber member **24** is supported by a frame **28** to which are mounted roller guides or wheels **30** which are aligned with and guided along a track **32**. A drive means, not illustrated, is provided and is coupled to the frame **28** for effecting motion of the frame and the supported member **24** along the track **32** for a distance sufficient for providing access to the free end of the mandrels which are then exposed by the displacement of this chamber member.

A plurality of substrate bodies **40, 42, 44** and **46** are mounted on an elongated rotatable mandrel **48** which is adapted for rotation about its longitudinal axis **49**. Additional rotatably mounted mandrels **50, 52, 54, 56** and **58** each having a plurality of substrate bodies mounted thereon are also provided. While six such mandrels each having four substrate bodies mounted thereon are illustrated in the drawings, it will be appreciated from the discussion herein that the number of mandrels and the number of substrate bodies which can be accommodated for vapor deposition can be varied.

The substrate bodies illustrated in FIGS. **1** through **3** are shown to comprise in one embodiment relatively thin, flexible, electrically conductive, seamless, endless belts formed, for example, of nickel, brass, aluminum or stainless steel. These belts typically have a thickness on the order of about 3 to 10 mils. In FIG. **3**, an endless belt **59** is shown supported by a pair of plastic, generally disc-shaped support form members **60** and **62** which are positioned back to back and are secured together by means, not illustrated, in order to form a configuration which is adapted for supporting the endless belt 59. The forms 60 and 62 each include apertures formed centrally therein and through which the mandrel 54 extends. A key means, not illustrated, secures this form assembly to the shaft 54 for rotation therewith. Longitudinal movement of the form assembly and its supported belts is restricted by a collar 64 which is secured to the shaft 54. An annular shaped coating mask 66 having an inwardly extending rib 68 is positioned on a surface of the inner belt. A similar mask 70 is positioned intermediate the belt 59 and an adjacent belt 72. These masks function to define edges of the areas of deposited photoconductor material on the belts, to space the belts on the mandrels, and to reduce generally the deposition of photoconductive material upon the mandrel. While FIGS. 1–3 illustrate the positioning of cylindrically shaped substrate belts in the chamber for the vapor deposition of a photoconductor material thereon, substrate support bodies comprising cylindrically shaped drums may equally well be positioned on the mandrels.

In addition to the cylindrical configuration thus far described, the substrate bodies can assume other configurations, as for example, a planar configuration as is illustrated in FIG. 12. The substrate bodies 51, 53, 55 and 57 of FIG. 12 are secured to surfaces of a support form 61 by clamps or hold downs, not illustrated. The support form is frame shaped and includes spokes 63 extending from these surfaces to a hub 65. The hub is positioned on and keyed to a mandrel 67 for rotation therewith.

A relatively efficient utilization of coating material, an enhanced randomization of photoconductor deposition on the support substrates, and an improved control of deposited film thickness is effected by providing a planetary rotational motion of the type wherein each of the mandrels is rotated about its horizontally extending longitudinal axis while the rotating mandrels are transported in a path extending in a substantially vertical plane. This desired epicyclic motion is effected by the provision of a rotary support body referenced generally as 73 which is formed by an annular shaped disc 74 having a plurality of radially extending arm segments 78–88 (FIG. 2) mounted thereto, such as by welding, and each of which supports hubs 90–100 respectively at a distal segment thereof. The arm segments are spaced apart and braced by struts 102–112 which extend between adjacent arm members near the distal located hub segments. Inner spacing and bracing struts 114–124 are positioned adjacent the plate 74 and are welded to the plate and to adjacent radial arm members. The plate 74 includes a centrally located aperture 123 (FIG. 3) formed therein and into which a hub 124 extends. The hub 124 which is welded to the plate 74 is a member of a hollow rotary drive shaft which further includes a heavy walled tubular member 126, a tubular shaft segment 128, a circular shaped plate 130, and a circular plate 132. These members are secured together by welding. The tubular drive member 128 extends through the vertically orientated vacuum chamber wall member 20 and through the backing wall or beam 22. There is mounted to an outer surface of the shaft 128 a pulley 134 which is engaged by a drive belt 136. A primary source of rotary motion comprising an electric motor 138 is provided and a drive pulley 139 is mounted on a drive shaft 140 of the motor. The drive shaft 140 causes rotation of the plate 74 and results in the transport of hubs 90–100 in an annular, and more particularly a circular, path extending in a vertical plane within the chamber.

As indicated hereinbefore, each of the substrate body support mandrels 48–58 is rotated about its horizontally orientated longitudinal axis. The mandrels are each rotatably supported and driven at one end thereof while an opposite end of the mandrel provides for mounting of the substrate support forms and belts thereon. FIG. 3 illustrates one end of the mandrel 54 extending through the hub 96. Roller bearings 150 and 152 are press fitted near end segments of a sleeve 154 which is fitted into a cylindrical bore in the hub 96. The mandrel 54 is thus rotatably mounted. A bevel gear 156 is mounted on the mandrel and is driven in order to impart rotary motion about a horizontally orientated, longitudinal axis of the mandrel. A rotary force for rotating the mandrel 54 is derived from a main bevel gear 158 and is coupled to the mandrel gear 156 through a bevel gear 160, a drive shaft 162 which is journaled in a body 164 and a bevel gear 166. The body 164 is welded to the rotary plate 74. Each of the spindles in the apparatus are similarly rotatably supported and derive rotation forces from the main bevel gear 158.

Rotary motion is imparted to the main bevel gear 158 independently of the rotary motion of the plate 74 by a drive shaft 170 which is concentrically positioned with respect to the tubular shaped rotary drive means which rotates the plate 74. The main bevel gear 158 is secured to the drive shaft 170 for rotation therewith. The shaft 170 is journaled within the tubular member 128 and extends through bearings 172, 174 and through the hub 124. A drive pulley 176 is mounted on the drive shaft and is driven by a belt 178 from an electric motor source 179 (FIG. 2). Thus, rotation of the drive shafts 128 and 170 result in an epicyclic motion of the substrate bodies. It is noted that the mandrels and the main support plate 74 are independently driven and their rates of rotation can advantageously be independently varied.

During the vapor deposition process, it is desirable to monitor the temperature of the substrate bodies. A thermocouple pickup junction 180 is secured by spring loading means, not shown, to an under surface of the substrate body 59. Thermocouple leads 182 and 184 extend from the junction 180, are fed through the substrate support body, through an aperture 186 in the tubular mandrel 54 and are dressed along an inner surface of the mandrel and are electrically coupled to slip rings 188 and 190 which are mounted on the mandrel shaft. Pickup brushes 192 and 194 are mounted in, and, are insulated from the sleeve 154 and leads extending therefrom are dressed through an aperture 196 in the sleeve 154 and through the hub 196 and are led to a thermal indicator and recorder, not illustrated.

A means for supporting a photoconductor material within the chamber 18 and for vaporizing the material comprises a planar array 200 of crucibles (FIG. 1) which are located within the vacuum chamber 18 and which are positioned within an annular path defined by the travel of the support mandrels. This planar array of crucibles is supported from an end wall segment 202 of the bell shaped housing member 24 and is transportable therewith. Thus, when the bell shaped housing 24 is separated from the wall member 20 the planar array of crucibles is similarly withdrawn. As the bell shaped member 20 is advanced toward and is closed upon the wall member 20, the planar array is thereby automatically positioned within the annular path defined by the epicyclic motion of the mandrels. An arrangement of the planar array of crucibles is described in greater detail hereinafter with respect to the embodiment of the apparatus disclosed in FIG. 4. For the present, it is noted that in the apparatus illustrated in FIGS. 1–3, the array 200 includes flanged support segments 204 and 206 which are mounted on a plate 208. The plate 208 is in turn supported on cross members 210 and 211 which are secured to a support beam assembly 214. The beam assembly 214 is mounted to a plate 216 which in turn is supported from the chamber wall segment 202. A support brace 220 extends between the beam assembly 214 and the plate 216. Although the array 200 of crucibles is shown to be centrally located within a circular path of travel of the mandrels, the array can be positioned at locations displaced from this central location. The crucible assembly can alternatively be located outside the annular path defined by the travel of the mandrels.

Prior to closure of the vacuum chamber, each of the plurality of boat shaped crucibles 222 in the array 200 have deposited therein a predetermined amount of photoconductor material which is to be deposited on the substrate bodies. The photoconductor material comprises for example selenium or alloys thereof.

Current conducting leads 224 and 226 extend from the chamber through feed through connections (FIG. 10) and are coupled to a crucible transformer 228 to which a voltage is applied from a line source 220 under the control of a temperature servo control means 232. The servo control 232 receives monitoring temperature information from one or more temperature sensors, not shown, such as thermocouples attached to the crucible array. The crucibles are made of a conductive material such as stainless steel and current flows therein thereby heating the crucible assembly 200 and causing the assembly to heat both the substrate support bodies which are transported within the chamber and the photoreceptor material. The temperature of the substrate bodies, which have a relatively low thermal mass and are supported by plastic forms having a relatively low thermal conductivity is increased to the desired coating temperature. The photoconductor material is heated to vaporization and deposits upon the surfaces of the support body substrate. Thus, the crucible assembly in addition to containing the photoconductor material and causing its vaporization further operates to heat the substrate support body to a desired temperature for satisfactory vapor deposition of the photoconductor material on the surface of the substrate.

Photoconductor alloys suitable for use with the present invention include, without limitation, selenium alloyed with arsenic, tellurium, thallium, antimony, bismuth and mixtures thereof. U.S. Pat. Nos. 2,803,542; 2,822,300; 2,745,327; 2,803,541; 2,970,906; and 3,312,548 illustrate in more detail suitable applications and process techniques for selenium and selenium alloys which may be used in carrying out the process or in using the apparatus of the instant invention. A particularly preferred photoconductive alloy suitable for use in the instant invention comprises selenium alloyed with arsenic in the range of from about 0.1 to 50 weight percent. U.S. Pat. Nos. 2,803,542; 2,822,300 and 3,312,548 more fully define such alloys and are incorporated herein by reference. Generally, when selenium is alloyed with arsenic, the vapor deposited photoconductive layers of such alloys exhibit an inherent fractionation which is characterized by a composition gradient in which greater concentrations of arsenic are found at the free surface of the alloy layer with the concentration of the arsenic decreasing towards the photoconductor-substrate interface. In using the process and apparatus of the instant invention, it has been observed that for very low arsenic concentrations (i.e., 0.1–0.75 wt. % As – balance selenium), that a relatively flat concentration gradient for the arsenic results.

In a typical coating operation, the substrate support bodies each comprise an electroformed, flexible, endless belt which is formed of nickel and which has a thickness of about 4.5 mils, a diameter of about 20 inches and a width of about 16½ inches. The substrate support bodies are cleaned and an organic interface, for example, is formed thereon by coating. The belts are initially mounted on the support forms which are fabricated of a material which offers sufficient support for preventing physical damage to the relatively delicate thin walled substrate, provides a thermal barrier for reducing the transfer of heat between the support and the substrate and is compatible with the vacuum process. Suitable materials from which these forms are fabricated comprise polypropolene and polystyrene. The coating masks which can be fabricated of plastic or metal are positioned on an edge of a form and the form is then mounted on the mandrel shaft. A plurality of such assemblies are mounted on the mandrel until the mandrel is loaded to capacity. A photoconductor material which comprises for example an alloy of selenium and arsenic is deposited in the individual boat shaped crucible members. It is noted that the loading process is greatly facilitated since the bell shaped member 24 which is withdrawn from the wall 20 and beyond the distal end segments of the mandrels provides ready access for the operator in performing the mounting operation. Further, the removal of the boat array from that area within the path traveled by the mandrels during the coating operation facilitates charging of the boats. The bell shaped member 24 is then closed upon the wall member 20 and the planetary motion of the mandrels is initiated by energizing the motors 138 and 180 [FIG. 2]. Typically, the tubular shaft assembly and the plate 124 mounted therefrom rotates at a rate of about 5 RPM. and the mandrels rotate at a rate of about 15 RPM. The vacuum pumping means is then activated and pump down proceeds until a pressure on the order of about 5×10^{-4} Torr is attained. Crucible power is then applied to the crucible assembly from the transformer 228 (FIG. 10) under the control of a time temperature control means 232. Prior to heating of the crucible assembly, the substrate bodies are at a temperature of about 25°C. The temperature control means 232 is adapted to increase the temperature of the crucible and of the substrate bodies in accordance with a predetermined temperature program. This means includes a closed loop control system which derives temperature indications from sensors located within the chamber. Temperature control and programming means of this type are well known in the art. During deposition, the temperature of the substrate bodies rises to a value within a range of about 70°–85°C. At this temperature, an acceptable photoconductor film is deposited which exhibits both desirable physical and electrical characteristics. The crucible will be maintained at the programmed temperature until the proper thickness of photoconductor material has been vapor deposited upon the substrate body. This is controlled by the amount of photoconductor material deposited in the crucibles, the time-temperature program provided by the control means, and the pressure within the chamber. When the proper thickness has been attained, crucible power is decoupled, the crucibles are cooled, and the chamber is then returned to atmospheric pressure.

In a typical operation, the cycle of events will include a vacuum pumping interval of about 9.5 minutes, a crucible heating interval of about 40 minutes, a dwell time of about 6 minutes during which time the temperature of components within the chamber decreases, and finally a depressurization interval of about 6 minutes during which the chamber is returned to atmospheric pressure.

The apparatus and method described herein advantageously provides for the simultaneous coating of a relatively large number of substrate bodies thereby providing a relatively efficient, economic, and high production capacity system. In addition, the planetary motion of the substrate bodies within the vacuum coating chamber requires substantially less coating material than prior techniques for an equivalent thickness. A relatively high degree of randomization of deposition occurs which enhances its uniformity of coating between different substrate support bodies. Quality control of the produced electrostatographic image retention surfaces is thereby greatly enhanced. For example, a photoconductor thickness measurement need only be taken on a deposited film associated with a single mandrel and this effectively measures the entire batch of photoreceptors. Not only is the uniformity of photoreceptor production enhanced but the labor involved in quality control of the photoreceptor is thereby reduced. Additionally, control of photoconductor thickness within a particular photoreceptor is more precise than prior arrangements. In addition to the advantageous uniform thickness of the characteristics attending the randomization provided by planetary coating, improved electrical characteristics of the photoreceptor are also realized in that the uniformity of electrical properties between different coatings is enhanced.

An alternative embodiment of an apparatus constructed in accordance with features of this invention is illustrated in FIGS. 4–11. Those elements of FIGS. 4–11 which perform functions similar to those performed by elements of FIGS. 1–3 bear the same reference numerals. In the embodiment of FIGS. 4–11, a plurality of mandrels 400, each of which are horizontally orientated are rotatably supported at one end thereof by a plate 402 (FIG. 4A). This plate is mounted on a drive shaft 404 and is journaled through the vertical wall plate 20 and its support beam 22 to a pulley 406 which is secured to an end of the shaft. The pulley is coupled via a drive belt 408 to a drive pulley 410 which is mounted on a drive shaft of a motor 412. Excitation of the motor 412 causes rotation of the drive pulley and a corresponding rotation of the plate 402. A ring shaped body 414 having a plurality of hubs 416 formed therein is mounted to and secured to the plate 402 for rotation therewith. The hubs, which are positioned in an annular array, each include a horizontally extending cylindrical bore 417 which functions as a journal for the mandrels 400 extending therethrough. A relatively large diameter spur gear 418 having gear teeth 419 formed on its peripheral surface is journaled about a segment 420 of the drive shaft 404. Longitudinal motion of the gear 18 is restricted by a drive shaft segment 422 of enlarged diameter and a collar 423. The gear 418 is therefore free to rotate independently of the rotation of the plate 402. The spur gear 418 includes an integral hub segment 423 having gear teeth 421 formed about a peripheral surface of the hub 423. The hub 423 is engaged and driven by a spur drive gear 424 which is mounted on a shaft 426. The shaft 426 which in FIG. 4A is shown by dashed lines extends through the vacuum chamber wall member 20 and the backup beam 22 and includes a pulley, not illustrated, mounted on an outer segment thereof which is driven by an electric motor 425 (FIG. 5). Each of the mandrels 400, which extend through a cylindrical bore 417 in the ring 414, has mounted to an end thereof a spur gear 428 which engages the gear teeth 419 of the gear 418. The plate 402 and the plurality of mandrels 400 are thus independently rotatable thereby advantageously providing means for independently altering their speeds of rotation.

The planar array 200 of crucible members which was referred to hereinbefore is formed by a plurality of boat shaped crucible members 222 (FIGS. 9 and 11). Each of these members includes flanged end segments 449 (FIG. 7) which are welded or bolted to the flanges of other members in order to form a plurality of cruible strips 450–467 (FIG. 11). The strips 450–459 extend substantially coextensively with the mandrels 400 while relatively shorter outrigger crucible strips 460–467 are provided and are positioned near ends of the array for assuring distribution of vaporized photoconductor material near opposite end portions of the vacuum chamber. The crucible members 222 are typically fabricated of stainless steel. Each of the crucible strips are supported above an associated longitudinally extending strip 208 by flange members 209 (FIG. 7) which are located along the length of a crucible strip. In addition, ceramic insulating spacers 468–471 are provided and are mounted to a flange 206 and a support block 207 at opposite ends of each strip for providing electrically insulated support and electrical terminations for the crucible strips. The strips 208 are mounted to a support strip 211 which extends in a direction normal to the strip and is secured to the beam 214. The beam 214 which comprises a rectangular shaped channel is welded to a plate 215 which in turn is mounted to a plate 216. The plate 216 is supported from an extending mount 218 wich is secured to an inner wall segment 202 of the vacuum chamber member 24. A brace 220 extends between the beam 214 and the plate 215 for providing additional support for the beam 214.

Heating current is applied to the planar array 200 of crucibles from the crucible transformer 228 (FIG. 10) under the control of the servo temperature control means 232. Current flows from this transformer via vacuum feed-throughs to the outrigger strips 464 and 467 of the planar array (FIG. 11). Adjacent crucible strips are strapped together by relatively heavy, flexible, conductive webbing 484 as best illustrated in FIGS. 6 and 8 in order to provide a series current flow path through the crucible strips of the array. The strapping arrangement and the current flow paths resulting therefrom are illustrated in FIG. 11 for one alternation of an

AC cycle by the directions of the arrows shown in the figure. This flow of current, as indicated hereinbefore, heats the crucible array and the substrate bodies and causes vaporization and deposition of the photoconductor material upon the substrate bodies. The current is applied in accordance with a predetermined time-temperature program in order to attain the desired variations in temperature and to thereby control the thickness of the photoconductor material which is deposited on the substrate bodies.

In accordance with another feature of this invention, means are provided for preheating the substrate bodies during their planetary travel within the chamber. This means is shown to comprise a plurality of glow bar assemblies **500–506** (FIGS. **6**, **7** and **8**). A relatively high potential is applied to the cathode of the glow bar assemblies causing a discharge in the space between the glow bars and the support substrate bodies which results in at least two advantageous effects. In addition to heating the rotating substrate support bodies which are transported in an annular path past the glow bar assemblies (FIG. **6**) to the desired temperatures for the deposition of the photoconductor material, the glow bar assemblies in the case of certain substrate body materials, such as aluminum, establish an interface surface on the substrate support bodies. This process then advantageously eliminates the need for preliminary processing the substrate support bodies by forming an interface surface thereon. Furthermore, it has been found that the establishment of this interface at a time immediately prior to the deposition of the photoconductor in an evacuated atmosphere results in an enhanced photoconductor characteristic over that provided by prior art apparatus wherein the interface was formed in ancillary apparatus and was then subjected to an additional time interval and handling under atmospheric conditions.

The glow discharge assemblies **500**, **502**, **504** and **506** each include and electrode comprising an elongated, electrically conductive glow bar member **508** which is positioned adjacent the annular path of travel of the rotating mandrels **400**. The glow bar member is spaced a radial distance from the mandrels **400** by adjustable spacing means for providing the desired discharge. The discharge will be dependent upon such factors as the amplitude of the potential applied to the glow bar, the chamber pressure, the nature of the residual gas in the chamber and the shape of the cathode. The electrode member **508** extends longitudinally and coextensively with the length of the mandrels **400**. It is supported at opposite ends by electrically insulating retaining plates **510** and **511** (FIG. 7) formed of ceramic for example. The glow bar is supported at locations along its length by a plurality of retaining means **512** each of which includes a screw member which extends between the glow bar and an elongated support plate **513**. The retaining means **512** also includes electrical insulating spacers for insulating the relatively high potential of the glow bar from the plate **513**. Glow discharge shields **515** are secured to the plate **513** such as by welding and extend in a direction normal to the plane of the glow bar. These shields function to shield and confine the glow discharge to the space immediately below the glow bar electrode **508**. The plate **513** is secured to an elongated rail **520** which has welded thereto, extensible radially adjustable support arms **522**. These support arms each include slots **523** extending longitudinally and are adjustably mounted by screw pairs **524** which extend through the slots **523** and through apertures **525** in the support plates **526** and **527**. The aperture pairs are positioned circumferentially about the support plates thereby providing for both radial and circumferential adjustment of the glow bars. These support plates are mounted to a channel shaped frame body **528** which is rigidly mounted to and suspended from the beam **214** by extending arms **530**. Stiffner rods **529** and **531** extend between and are welded to the plates **526** and **527**. An electric potential is applied to the glow bar member **508** through a lead **530** which is coupled to each of the glow bar members through a vacuum sealed feed from the power source **518** (FIG. **10**).

In operation, the bell shaped chamber **24** (FIG. **4B**) is withdrawn from union with the wall member **20** (FIG. 4A). The chamber member **24** is withdrawn beyond the distal segments **600** of the mandrels **400** for providing access for mounting a plurality of tubular shaped substrate bodies **602** on each of the mandrels. A plurality of edging masks **604** are provided and positioned between the substrate members on a mandrel in order to define an edge for the deposited coating. In a typical example, the substrate body **602** comprises a tubular body formed of aluminum and has a nominal diameter of about 3½ inches, a length of about **16** inches, and a wall thickness of about three-sixteenths of an inch. It is noted that the substrate bodies need only have been previously cleaned before mounting on the mandrels. The boats of the crucible array are charged with a photoconductor material, referred to in detail hereinbefore. The bell shaped housing member **24** is then advanced into contact with the wall member **20** in order to provide a vacuum tight seal. The electric motors are energized in order to rotate shafts **404** and **426** and to initiate the planetary motion of the substrate bodies within the chamber. A vacuum pumping operation is initiated by activating the vacuum pumping means. In a typical example, the plate **402** is rotated at a rate of about 5 RPM and the mandrels **400** are rotated at a rate of about 15 RPM. Pump down of the chamber proceeds until the chamber pressure has reached a value on the order of 10 to 50 milli-Torr. This chamber pressure, when established, is maintained by a pressure sensing transducer which operates in conjunction with the vacuum pumping means. A gas is admitted to the chamber by a control leak during this period of time. The gas can comprise air which has been conveyed through a moisture removing device. Other gases such as oxygen may also be employed. With the chamber pressure maintained within the desired range, the glow discharge process is initiated. A voltage of between 1,000 and 5,000 volts is applied to the electrode elements which establishes a high voltage plasma between the glow bar cathodes and the substrate body anodes. This plasma discharge preheats the substrates prior to initiation of the vapor deposition of the photoconductor material on the substrates. Additionally, the plasma discharge functions to establish an interface on the aluminum substrate by forming a thin aluminum oxide film on the outer surfaces of these bodies. The plasma discharge continues until a substrate temperature on the order of about 40°C. to about 75°C. is attained. The control leak is shut off and pump down is again initiated in order to reduce the pressure within the chamber to a pressure on the order of about 5×10^{-4} Torr or less. Electrical power is then applied to the crucible assembly for heating the crucibles and causing vaporization of the photoconductor material contained therein. The closed loop temperature control means 232 provides for controlling the temperature of the crucible in a programmed manner. Power is applied to the crucible from the alternating power source 220 through the transformer 228 under the control of temperature programm control means 232. The substrate temperature then generally exhibits an increase in temperature of about 10°C. to 15°C. during the application of power to the crucible assembly. Power will be applied under program control until the desired alloy thickness is established. At this time, power to the crucible assemblies is interrupted and a cooling dwell time is provided. The vacuum chamber is then returned to atmospheric conditions.

In a typical cycle of events, the initial evacuating operation is performed in 12 minutes; the glow discharge is performed in 10 to 55 minutes; the further reduction in vacuum within the chamber occurs in about 1 minute; the power is applied to the crucibles for between about 25 to 60 minutes; the temperature cooling dwell time is about 5 minutes; and the pressurization to atmospheric pressure occupies approximately 5 minutes.

The embodiment of this invention described with respect to FIGS. 4–11 is particularly advantageous in that it eliminates the need for the preliminary formation of an interface on the substrate bodies. In addition to eliminating this step, the interface formed by this method provides improved characteristics in the photoreceptor since the interface is formed under evacuated conditions immediately prior to deposition of the photoconductor material and further handling and exposure at atmospheric conditions is avoided.

There has thus been described an improved method and apparatus for fabricating an electrostatographic image retention surface by the vacuum deposition of a photoconductor material on a substrate support body. The method and apparatus provides for the epicyclic motion of a plurality of substrate bodies which are horizontally orientated on a rotating mandrel. A plurality of such mandrels are provided and a relatively large number of substrate bodies are thereby rotated while they are simultaneously coated by the evaporation and deposition of the photoconductor material. Additionally, a glow discharge means is provided which establishes an interface on the substrate body, which preheats the body to operating temperatures prior to vacuum deposition, or which both forms the interface and preheats the body. The described method and apparatus are advantageous in that an improved distribution of photoconductor material is provided for a useful range of film thicknesses; a more efficient use of the photoconductor alloy is effected; an enhanced randomization of deposition takes place thereby resulting in an improved film thickness control; the intermediate step of chemically treating a substrate body for establishing an interface is avoided and an enhanced photoconductor film results therefrom; and, mounting and demounting of a relatively large number of substrate support bodies on the mandrels is provided thereby resulting in an increased economical use of production equipment and an increased rate of production of electrostatographic image retention surfaces.

While there has been described a particular process and apparatus for carrying out the invention, it will be understood that various modifications may be made thereto without departing from the spirit of the invention and the scope of the appended claims.

What is claimed is:

1. Apparatus for the vapor deposition of a layer of material on substrate bodies comprising:

a generally vertically oriented support table adapted for rotation about a horizontal axis;

means for rotating said support table;

a plurality of elongated horizontally oriented mandrels rotatably supported in an annular array on said support table;

means for rotating each of said mandrels about a longitudinal axis thereof;

each of said mandrels adapted for receiving, supporting, and rotating therewith a plurality of substrate bodies;

means for vaporizing a predetermined quantity of material which is to be deposited upon said substrate bodies;

heating means including an electrode mounted and adjustably positioned adjacent the annular path of travel of said mandrels and extending substantially coextensively with the elongated mandrels, means for applying an electric potential between said electrode and said substrate support bodies for establishing a glow discharge between said electrode and said substrate support bodies for forming an interface barrier layer on said support bodies; and

means providing an evacuated enclosure for said heating means, mandrels, and the substrate bodies supported thereon.

2. The apparatus of claim 1 wherein said means for vaporizing said material is positioned substantially outside an annular path of travel of said mandrels.

3. The apparatus of claim 1 wherein said means for vaporizing said material is positioned substantially within an annular path of travel of said mandrels.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,845,739 Dated November 5, 1974

Inventor(s) Francis J. Erhart and Harold H. Schroeder

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 4, eliminate "continuation".

Column 4, line 1, "18" should be --18--.

Column 5, line 43, "73" should be --73--.

Column 6, line 59, "200" should be --200--.

Column 7, lines 9, 17, 24 and 39, "200" should be --200--.

Column 10, lines 25 and 56, "200" should be --200--.

Signed and sealed this 14th day of January 1975.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents