ELECTROFORMING SYSTEM

Filed May 8, 1972 7 Sheets-Sheet 1

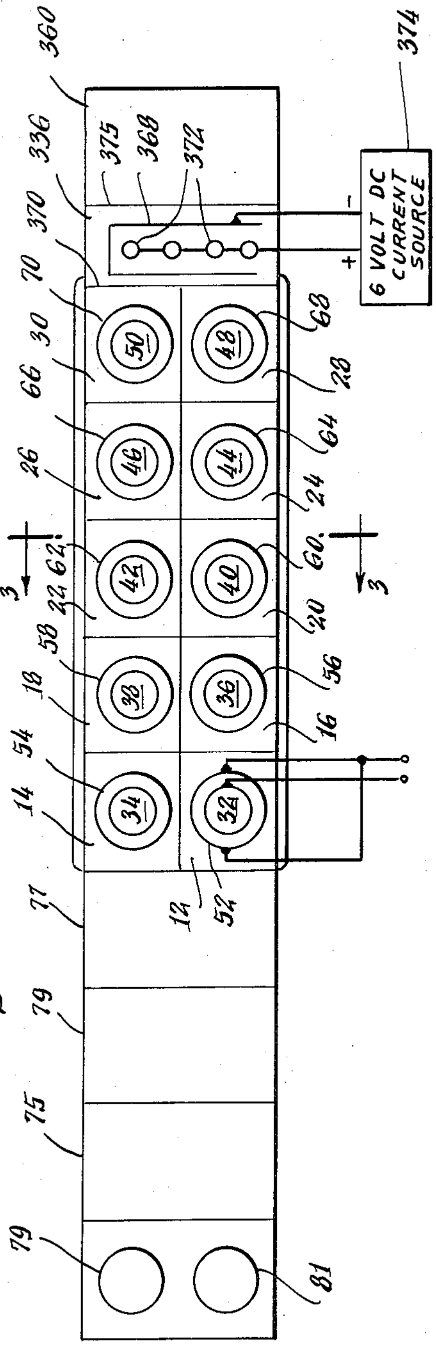

Fig. 2.

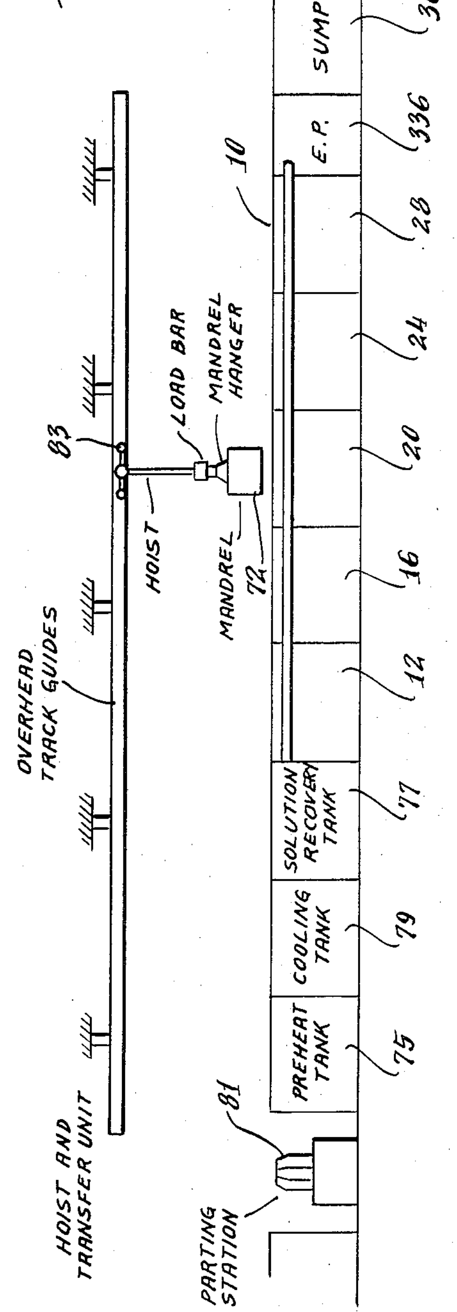

Fig. 1

March 26, 1974 E. M. WALLIN 3,799,859

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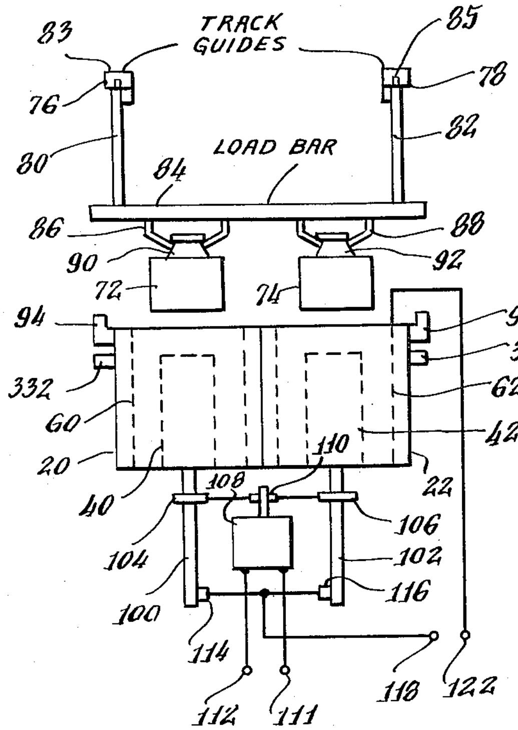


Fig. 3

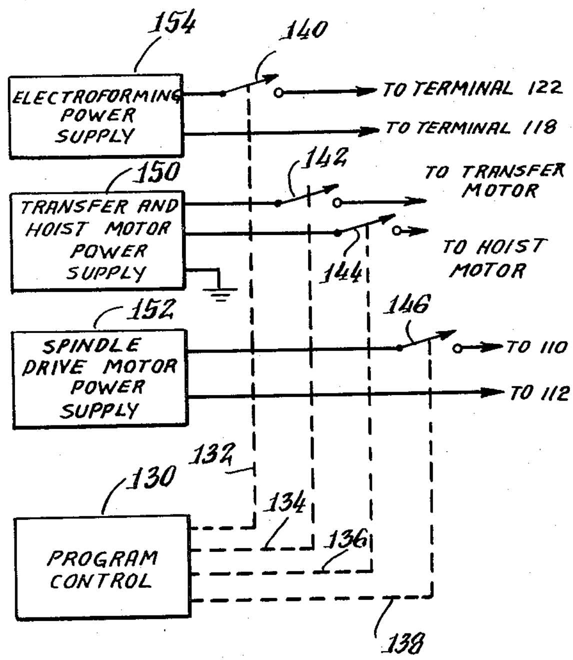
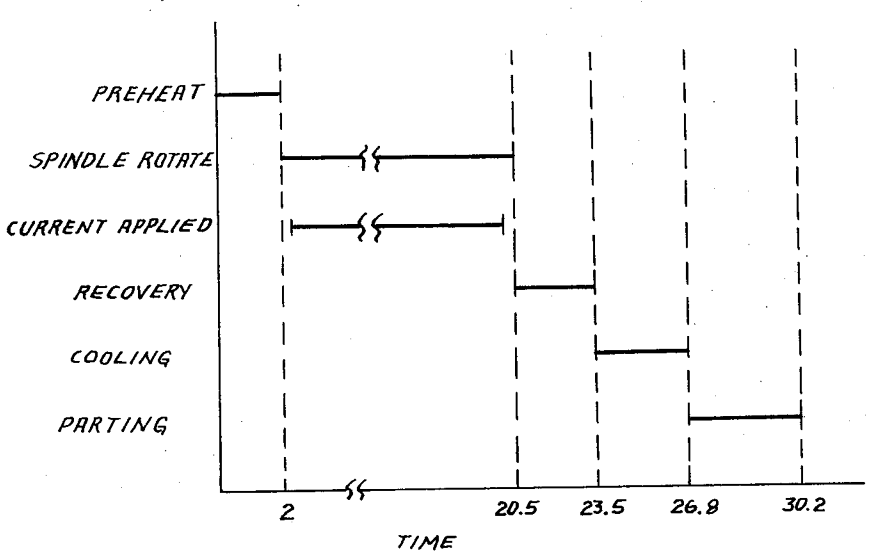
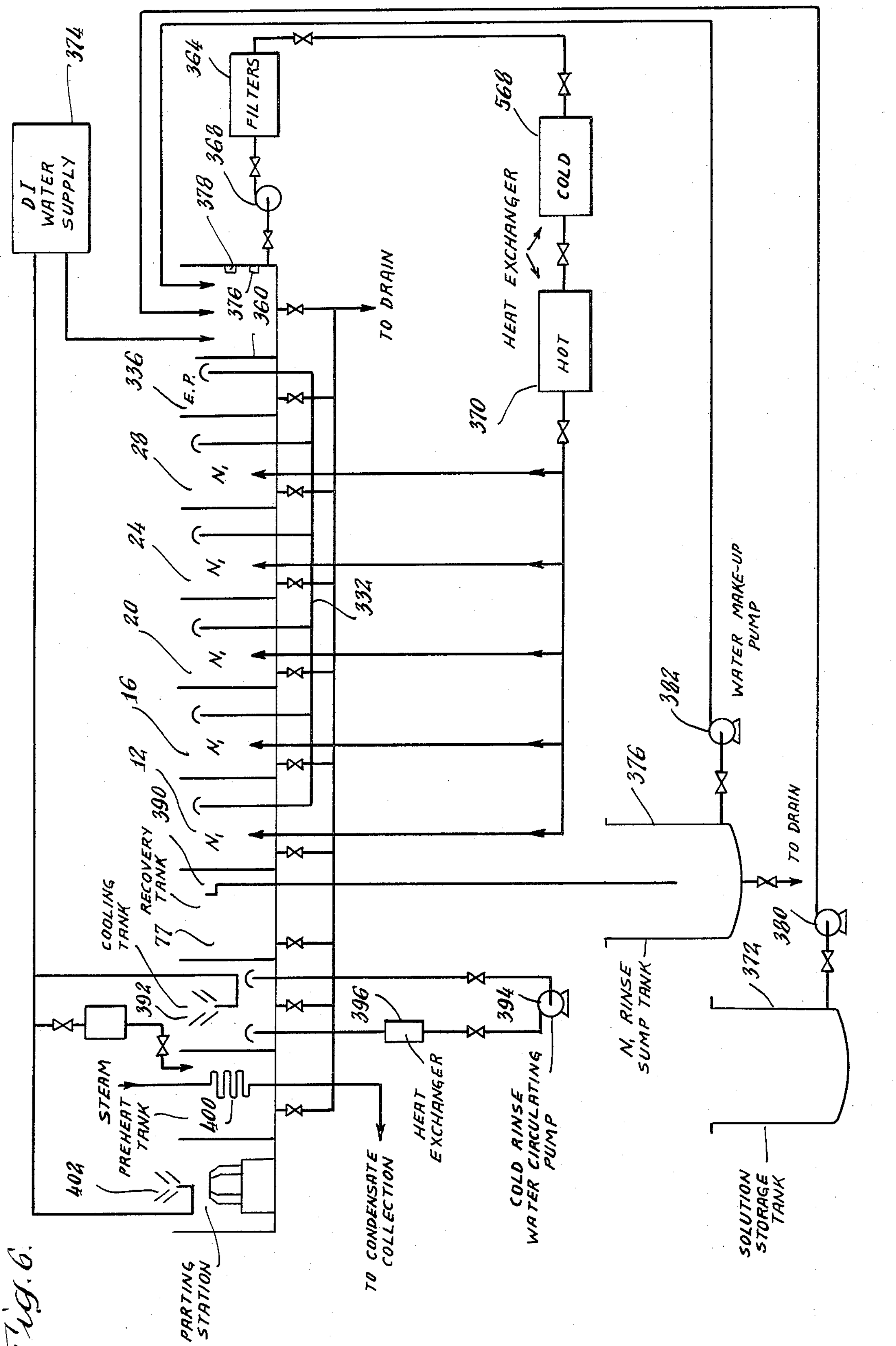


Fig. 4

Fig. 5





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DI WATER SUPPLY
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TO DRAIN
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RECOVERY TANK
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COOLING TANK
392
STEAM
PREHEAT TANK
400
402
PARTING STATION
TO CONDENSATE COLLECTION
396
HEAT EXCHANGER
394
COLD RINSE WATER CIRCULATING PUMP
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Ni RINSE SUMP TANK
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WATER MAKE-UP PUMP
TO DRAIN
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SOLUTION STORAGE TANK

Fig. 6.

Fig. 7

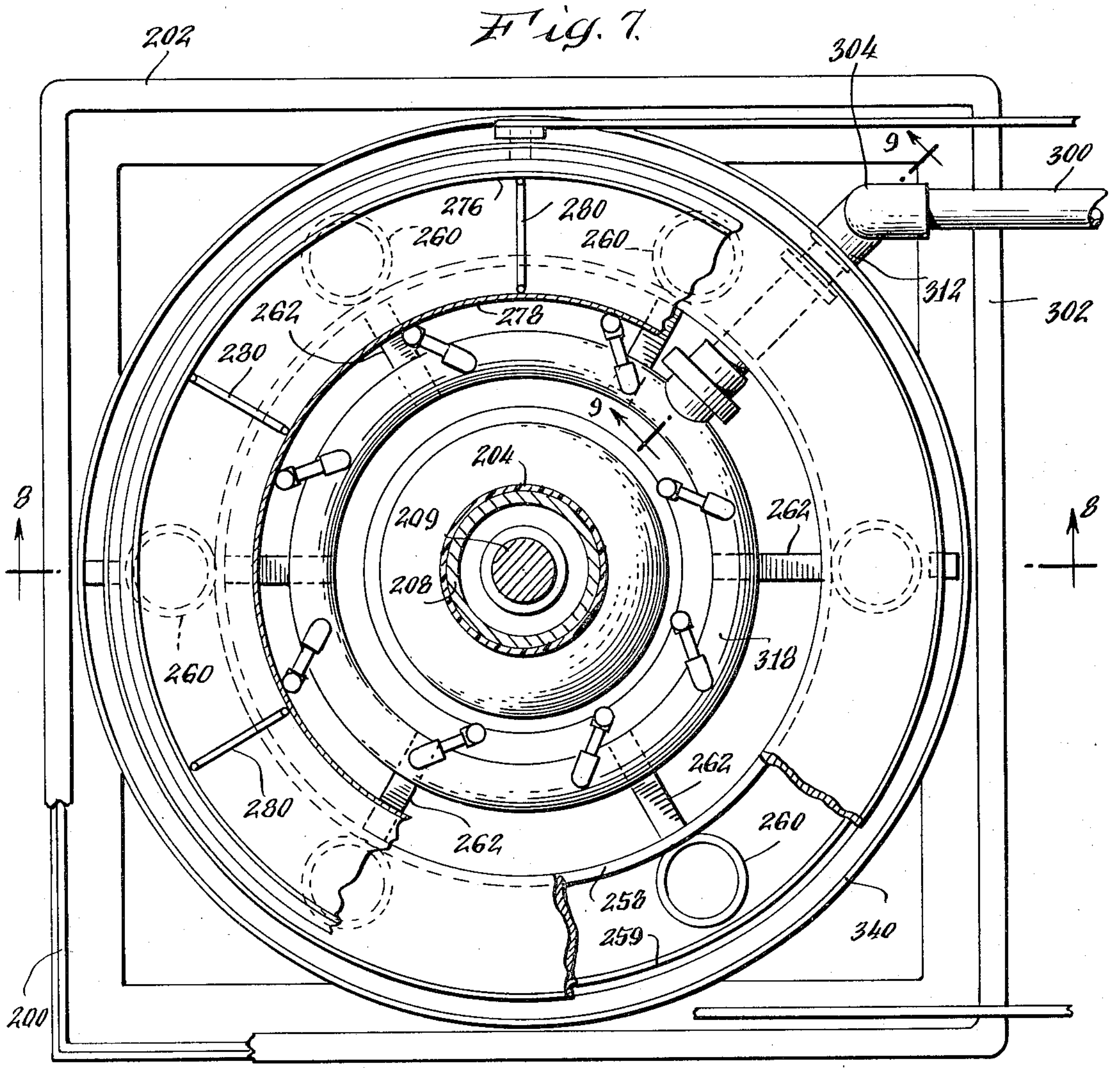
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Fig. 9

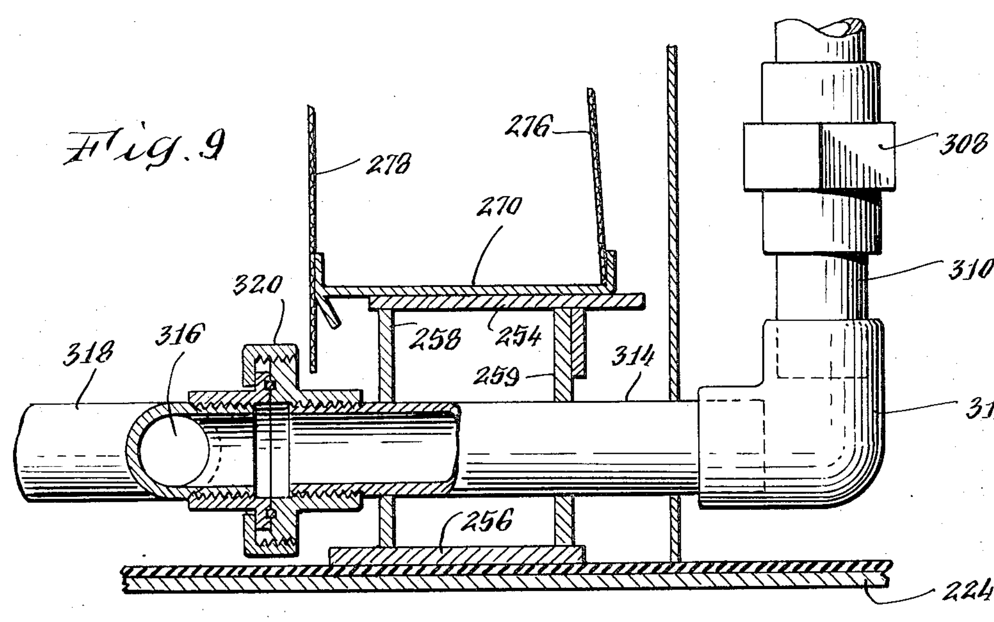
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Fig. 8.

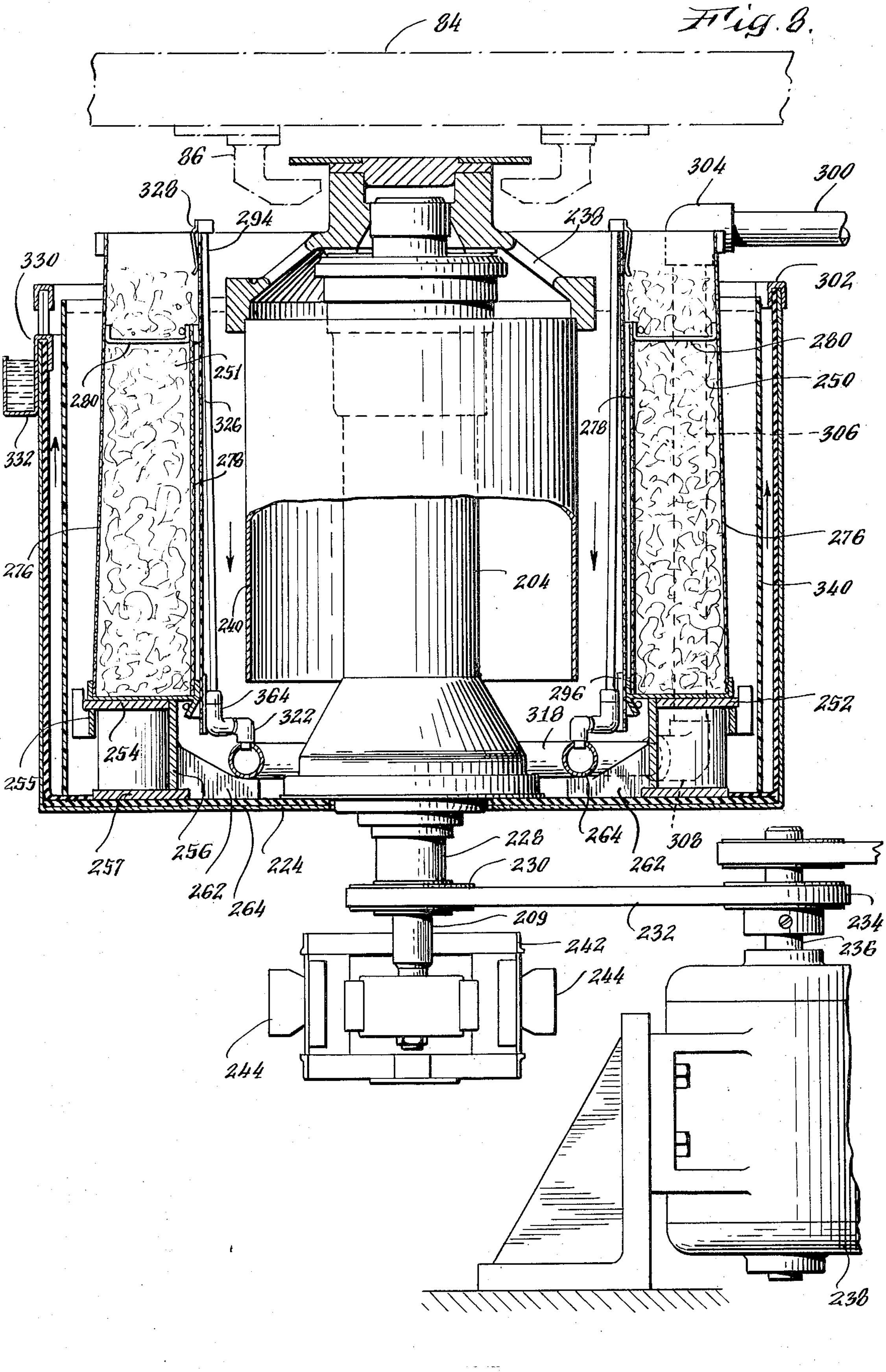
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Fig. 10.

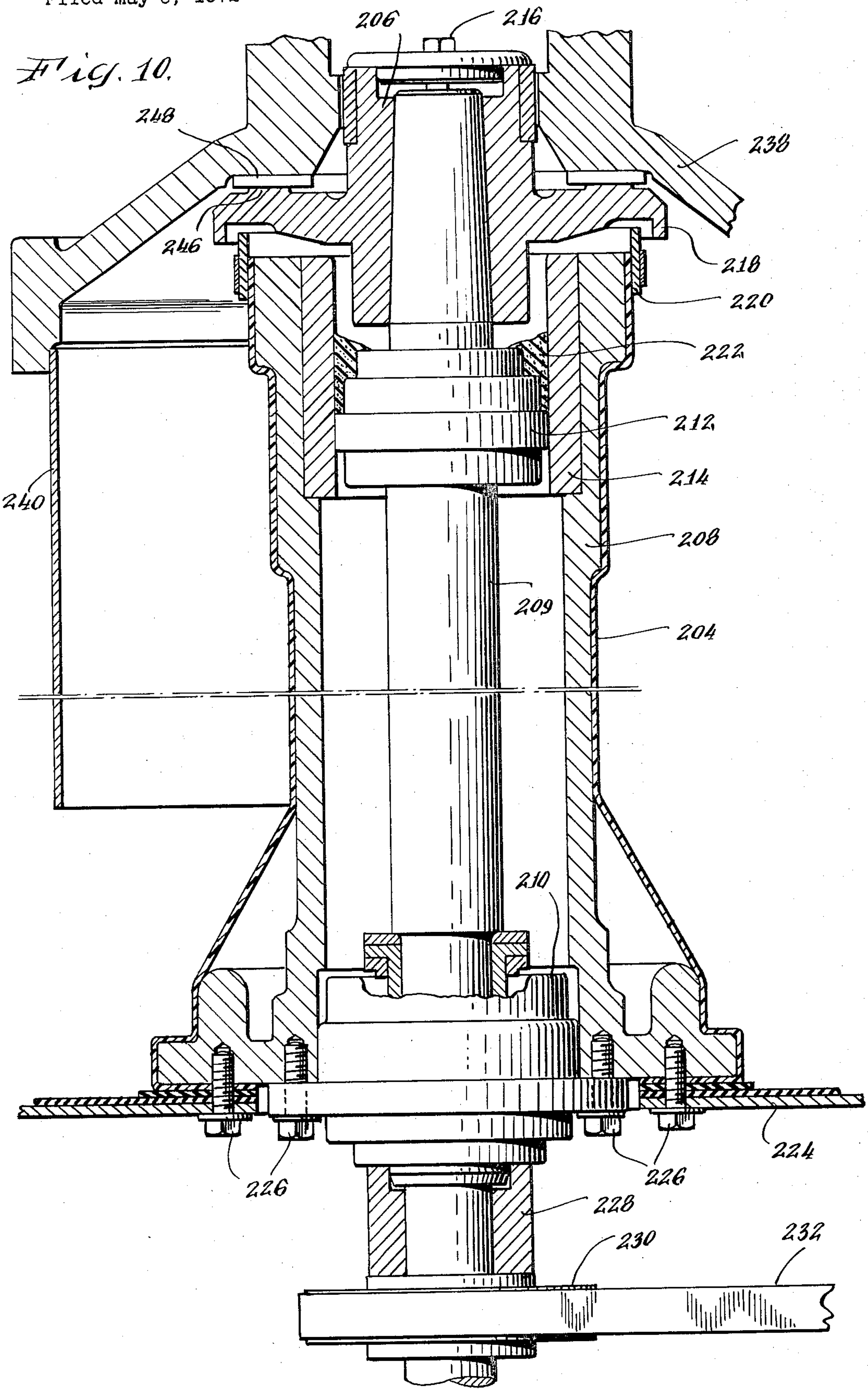
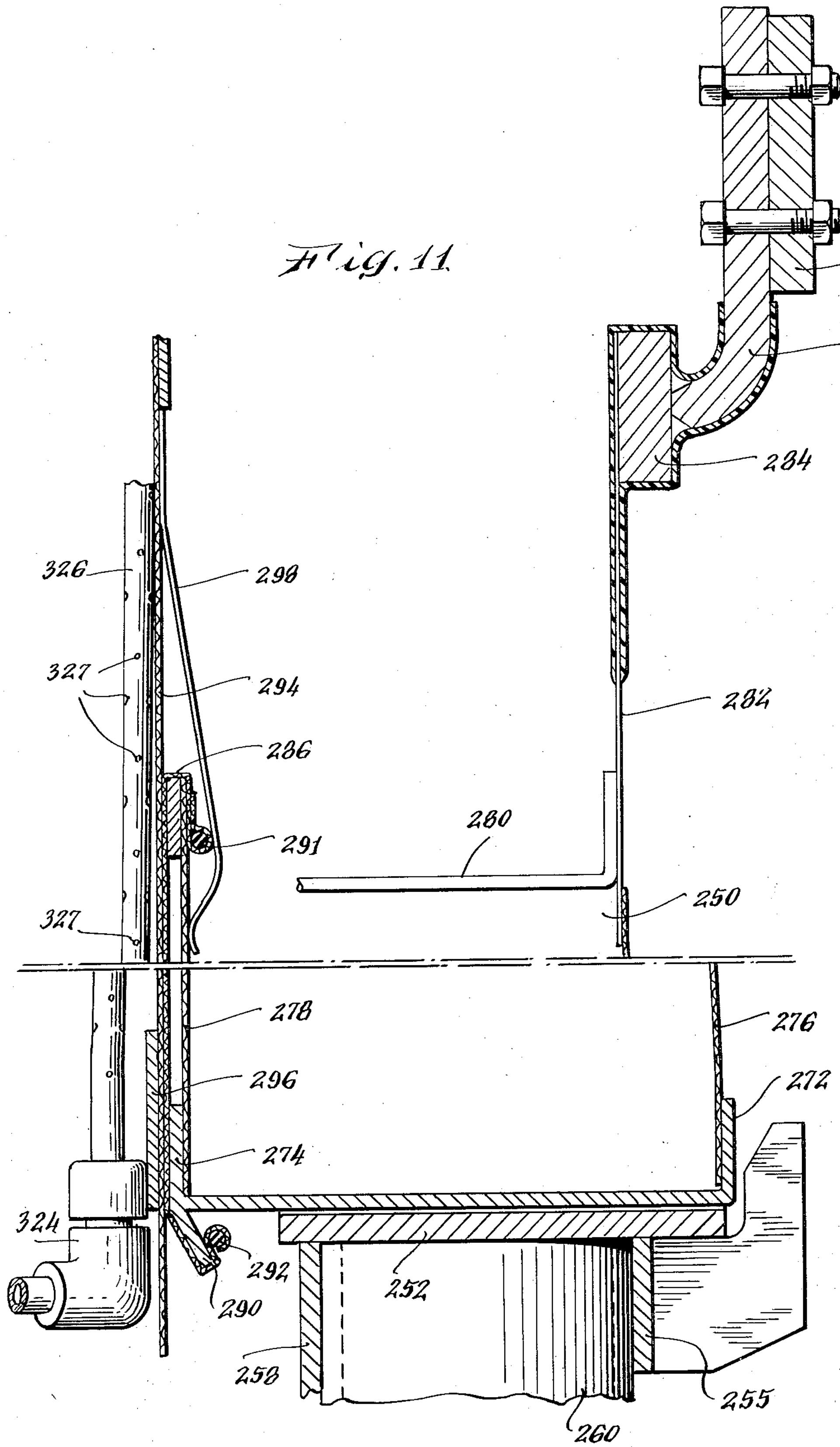


Fig. 11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ELECTROFORMING SYSTEM

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U.S. Cl. 204—216 12 Claims

ABSTRACT OF THE DISCLOSURE

A method and apparatus is disclosed for forming a relatively thin, flexible, electrically conductive endless belt on a support mandrel wherein the mandrel and belt exhibit different temperature coefficients of expansion. The method comprises the steps of preheating the support mandrel to a temperature of a plating solution, positioning the preheated mandrel in an electrolytic cell containing the plating solution, rotating the mandrel in the solution for an interval of time sufficient for depositing a film of predetermined thickness on a surface of the mandrel, and withdrawing the mandrel and an endless belt formed thereon from the solution and cooling the mandrel and belts in a cooling bath for facilitating the removal of the belts from the mandrel.

This invention relates to electroforming processes and apparatus. The invention relates more specifically to an improved electroforming process and apparatus for efficiently producing at a relatively high rate, a thin, flexible, seamless metallic band or endless belt. Endless belts of this type have particular usefulness in improved electrostatographic reproduction apparatus.

In the field of electrostatographic reproduction, an image is reproduced by initially establishing a latent electrostatic image on an image retention surface. The image retention surface typically comprises a layer of light sensitive material such as vitreous selenium formed on an electrically conductive substrate body. The image is developed by contacting the surface with a developer material which comprises, for example, a pigmented, electroscopic, thermoplastic resin. This developer material adheres to the photosensitive surface in image configuration and is subsequently transferred to a record medium such as a web or sheet of paper to which it is then fixed.

In commercial practice, the photosensitive material has been deposited on a conductive body substrate generally comprising a cylindrically shaped body or drum which is rotated about an axis thereof through charge formation, image formation, developing, and image transfer stations. Although apparatus incorporating a drum shaped support body has met with wide commercial acceptance, the use of a drum introduces certain limitations in the design and construction of the apparatus which can be overcome by the use of a flexible substrate support body formed as a band or an endless belt. However, an endless belt support body for use with an electrostatographic reproduction apparatus should, in addition to being electrically conductive and flexible, be seamless in order to avoid the necessity for indexing the operation of the machine to inhibit image formation at a seam of the belt.

An electrically conductive, flexible, seamless belt for use in an electrostatographic apparatus can be fabricated by an electroforming process wherein a metal from which the belt is fabricated is electrodeposited on a cylindrically-shaped form or mandrel which is suspended in an electrolytic bath. The materials from which the mandrel and the electroformed band are fabricated are selected to exhibit differing coefficients of thermal expansion for facilitating removal of the band from the mandrel upon cooling of the assembly. In one electroforming arrangement, the mandrel comprises a core cylinder formed of aluminum which is overcoated with a thin layer of chromium and is supported and rotated in a bath of nickel sulfamate. A thin, flexible, seamless band of nickel is electroformed by this arrangement. An electroforming process of this type along with suitable mandrels are disclosed in copending U.S. patent applications of Donald G. DuPree, Ser. No. 7,289, filed on Jan. 30, 1970, and Ser. No. 89,215, filed Nov. 13, 1970, now abandoned, the disclosures of which are incorporated herein. Each of these copending applications is assigned to the assignee of this invention.

An endless belt for use in electrostatographic apparatus will generally have a wall thickness on the order of about .003 to .010 inch and preferably exhibits certain desirable surface characteristics. More particularly, because the endless belt employed in an electrostatographic apparatus is overcoated with a photoconductive material such as vitreous selenium, the quality of images reproduced by the apparatus with an image retention surface of this character requires that the endless belt exhibit a high degree of thickness uniformity and have a surface with a high degree of smoothness. In addition to these mechanical characteristics, it is desirable to fabricate flexible, ductile, endless, seamless belts of this type which have relatively high tensile strength in an efficient, relatively economic manner and at a relatively high rate.

Accordingly, it is an object of this invention to provide an improved electroforming method and apparatus for fabricating relatively thin, seamless, electrically conductive endless belts.

Another object of this invention is to provide a method and apparatus for electroforming relatively thin, seamless, electrically conductive, endless belts for use in electrostatographic reproduction apparatus.

Another object of the invention is to provide an improved method and apparatus for electroforming a relatively thin, flexible, seamless, electrically conductive endless belt having a relatively high degree of thickness uniformity.

Another object of the invention is to provide an improved method and apparatus for electroforming a relatively thin, flexible, electrically conductive seamless endless belt having a relatively high degree of surface smoothness.

Another object of the invention is to provide an improved method and apparatus for efficiently electroforming at a relatively high production rate, a relatively thin, flexible, seamless, electrically conductive, endless belt having a uniform thickness and having a high degree of surface uniformity and smoothness.

A further object of the invention is to provide an electrolytic cell which reduces thermal gradients throughout the depth of an electrolyte used therewith.

Another object of the invention is to provide an electrolytic cell which reduces stratification in an electrolyte which is circulated through the cell.

Another object of the invention is to provide an improved electrolytic cell for electroforming endless belts on a rotating demountable mandrel and which is adapted for facilitating the entry to and removal of the mandrel from the cell.

Another object of the invention is to provide an electrolytic cell for electroforming endless belts having an improved mandrel support and rotating means.

Another object of the invention is to provide a relatively efficient endless belt electroforming method which recovers plating solution carried away from an electroforming cell by a formed belt and support mandrel.

In accordance with features of the method of this invention, a relatively thin, flexible, electrically conductive endless belt is electroformed by preheating an electrically conductive mandrel having a relatively smooth surface at a preheating station to a predetermined plating bath temperature; transporting the mandrel from the preheating station to an electroforming cell containing an electrolyte and positioning the mandrel on an upstanding electrically conductive rotatable spindle which is centrally located within the cell; rotating the spindle and the mandrel and applying a DC potential between the rotating spindle and a concentrically located donor metal container which is positioned within the cell for an interval of time for electrodepositing on the mandrel an endless belt of predetermined thickness; withdrawing the mandrel and the band formed thereon and transporting and positioning the mandrel in a plating solution recovery bath; withdrawing the mandrel from the recovery bath and positioning the mandrel in a cooling bath for cooling the mandrel and electroforming band whereby the belt which exhibits a differing thermal coefficient of expansion with respect to the mandrel can be removed from the mandrel; and, transferring the mandrel from the cooling bath to a parting station at which station the band is removed from the mandrel. In accordance with other features of the method of this invention, a plating solution for the electroforming cell is recirculated through stations for performing electrolytic purification, filtering and temperature control of the solution. A liquid contained in the recovery bath is introduced into the plating solution recirculation loop thereby forming a closed fluid flow loop for recovering plating solution which is carried away by the mandrel from an electroforming cell.

In accordance with features of the apparatus of this invention, an electroforming apparatus includes an electroforming cell comprising a tank containing an electrolyte and a vertically orientated rotary drive means positioned centrally within the tank and adapted for receiving, mechanically engaging, and electrically contacting a cylindrically shaped form which is lowered onto a hub of this drive means. A cylindrically shaped basket containing plating or donor material is concentrically positioned in the tank with the drive means. An electroplating current is provided by means which apply a DC potential between the donor metal anode basket and the rotary drive means. The means for applying the DC potential to the spindle is arranged for permitting unobstructed positioning on and removal of the form from the hub. An electrolyte is provided and is recirculated by means which convey the electrolyte to the cell at a location intermediate the plating form and the donor basket and a means is provided for inhibiting stratification of the electrolyte during recirculation thereof. This latter means comprises a baffle positioned intermediate the cell tank walls and the donor basket. In accordance with other features of the apparatus of this invention, two or more cells are juxtaposed and means are provided for simultaneously conveying an equal number of forms to associated cells.

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 elevational view of an electroforming apparatus constructed in accordance with features of this invention;

FIG. 2 is a plan view of the apparatus of FIG. 1;

FIG. 3 is a view taken along lines 3—3 of FIG. 1;

FIG. 4 is a schematic diagram of a program control means for automatically controlling the operation of the apparatus of this invention;

FIG. 5 is a timing diagram illustrating the occurrence of events in minutes in the apparatus of FIG. 1;

FIG. 6 is a process flow diagram illustrating the flow of and conditioning of electrolyte in the apparatus of FIG. 1;

FIG. 7 is a plan view of an electroforming cell of FIG. 1;

FIG. 8 is a view taken along lines 8—8 of FIG. 7;

FIG. 9 is a view taken along lines 9—9 of FIG. 7;

FIG. 10 is an enlarged sectional view, partly cut away illustrating the rotary drive means and mandrel arrangement utilized in the cell of FIG. 5; and

FIG. 11 is an enlarged sectional view partly cut away illustrating the donor basket employed in the electroforming cell of FIG. 5.

Referring now to FIGS. 1 through 5, the electroforming apparatus illustrated therein is shown to include a tank **10** which is segregated into a plurality of electroforming cells **12** through **30**. The cells each include an associated rotary drive means referenced generally as **32** through **50** and an annular anode basket designated by the circular ring in FIGS. 1 through 3 and referenced generally as **52** through **70**. The rotary drive means **32** through **50** and the anode baskets **52** through **70** are similarly formed and are described in greater detail hereinafter. During the electroforming process, hollow cylindrically shaped mandrels **72** and **74** (FIG. 3) lowered onto rotary drive means in juxtaposed cells **20** and **22**, for example. The mandrels are transported to the cells by an overhead hoist which supports a mandrel load bar **84**. The load bar includes collars **86** and **88** which are secured thereto for engaging the mandrels for transport. A control means, (FIG. 4), is provided for programming the operation and movement of the hoist and the operation and rotation of the rotary drive means **32** through **50**. When the motion of the transport is terminated above a processing station as for example above an electroplating cell, it will be accurately positioned over two juxtaposed cells for lowering of the mandrels onto the associated hubs of rotary drive means of the cells. As the load bar is lowered, the hubs engage an inner under side of the mandrel hangers **90** and **92** and unweight the mandrel holders from the support collars **86** and **88**. The load bar continues descending until the load bar **84** is engaged by saddles **94** and **96** which are formed on opposite walls of the tank **10** and which are located on an outer wall segment of each cell. At this location, the mandrels are then clear of the collars and are supported and can be freely rotated by the rotary means.

Rotation is then effected by the program control means (FIG. 4) and DC power is subsequently applied between a drive shaft of the rotary means and the anode basket. The mandrel is rotated for a predetermined period of time under the control of the program control means in order to electroform on the outer surface of the mandrel an endless belt of predetermined thickness. A means for transporting the mandrels through the different operating stations includes a hoist transfer unit having track guides **76** and **78** which are suspended from above the processing stations. The hoist transfer unit includes motor driven track guides **83** and **85** which engage and travel along overhead track rails **76** and **78**, respectively. The load bar **84** from which the spindles are suspended is supported from the track guides by motor driven hoist cables **80** and **82**. The load bar collars **86** and **88** engage a lower surface of mandrel hangers **90** and **92** of the mandrels **73** and **74**, respectively. At the termination of the electroforming interval, the load bar automatically is raised by the hoists thereby once again engaging thet mandrel collars **86** and **88** and removing the mandrels and endless belts formed thereon from the cell.

The general arrangement of an electroforming cell constructed in accordance with features of this invention is illustrated in FIG. 3. Each of the rotary drive means **40**, **42** include drive shafts **100** and **102**, respectively. A drive pulley **104** is provided for drive shaft **100** and a drive pulley **106** is simultaneously provided for drive shaft **102**. An electric drive motor **108** is provided for the juxtaposed cell pair for simultaneously rotating the rotary drive means of each cell. In FIG. 3, the drive motor **108** is shown to include a drive pulley **110** positioned on a drive shaft thereof. A drive belt **112** is provided and engages the drive pulley **110** as well as the pulleys **104** and **106**. Thus, when a motor energizing potential is applied to the terminals **111** and **112** of the motor **108**, the drive shafts will be simultaneously rotated.

During the electroforming process, a relatively low DC potential source having a relatively high current capacity is coupled between the mandrels **72** and **74**, which function as cathodes for cells **20** and **22**, respectively, and the anodes **60** and **62** of cells **20** and **22**, respectively. The cell arrangement illustrated is particularly advantageous in that an unobstructed path is provided for entry and withdrawal of the mandrels to each of the juxtaposed cell paths. This is accomplished in accordance with a feature of this invention by providing conductive drive shafts **100** and **102** and by coupling a cathode potential from the DC electroplating power source to these shafts. More particularly, each of these shafts includes a slip ring positioned thereon at a location on the shaft beneath a lower surface of the cell tank. Current contact brushes **114** and **116** are provided for effecting contact with the slip rings of these shafts. Each of the brushes is coupled to a terminal **118** to which the negative DC electric plating potential is applied. A positive potential is applied to the anodes **60** and **62** via a bus bar **120** and control terminal **122**. Each of the cell pairs is arranged in a similar manner.

Automatic operation of the electroforming apparatus is accomplished through a program control means illustrated schematically in FIG. 4 The program control means **130** comprises for for example a conventional motor driven program drum having activating contact elements positioned thereon for effecting electrical contact with stationary contact elements which, for example, cause the excitation of relay element in predetermined sequences and causing the application of operating potentials to the various drive motors and electroforming terminals described herein. For example, the dashed lines **132** through **138** of FIG. 4 represent relay lines which when excited by a control drum will effect closure of the contact **140** through **146**. These contacts will be closed in a predetermined sequence in accordance with the arrangement of contact elements on the drum and cause the desired transport of the mandrels, activation of the rotary means in the electroforming cells, and the applications of electroforming power to the cells. In a typical operation, the program control drum will during its rotation cause energization of line **134** thereby closing contacts **142**. A transfer motor of the hoist transfer unit is thereby energized by a potential which is applied from a power source **150**. This potential is applied for a predetermined period of time. The transfer motor effects transfer of the load bar and suspended mandrels to a desired processing station. At a predetermined location over the processing station, the program control will de-energize line **134** and energize line **136** thereof closing contacts **144** and causing the hoist to lower the mandrel into an operating position at the processing station. When the mandrel is properly located, the line **134** is deenergized and the contacts **144** are opened interrupting the application of potential to the hoist motor. When, for example, the mandrel is located at a processing station comprising the electroforming station, the program control will initially cause energization of the line **138** closing the contact **146** and applying potential from source **152** to the motor **108** of the rotary drive means. The mandrel supported thereon will then rotate. After rotation of the mandrel effected, the program control **130** will further cause energization of the line **132** and closure of the contact **140** thereof applying a DC electroforming potential to the cell via the contact **140** and terminals **122** and **118**. After a predetermined interval of time at the electro-forming station, the line **132** will initially be de-energized and the line **138** subsequently de-energized thereby interrupting the application of power to the motor **108** and interrupting rotation of the mandrel. The mandrel is then withdrawn from juxtaposed cells by energization of the various lines from the program control and the mandrel and electroform belt are transported to the solution recovery and cooling stations and then to the belt parting station. FIG. 5 illustrates the interval of times for different events occurring during the electroforming and processing of a pair of endless belts.

The program control arrangement of FIG. 4 comprises a conventional programming system for automatically controlling thet initiation and termination of steps in the electroforming process. Accordingly, in order to simplify the drawings, the details of the various lines for effecting both forward and reverse motion of the load bar, up and down motion of the hoist as well as other details as would be apparent to those skilled in the art are not illustrated. Furthermore, while the electroforming process described with respect to FIGS. 1 through 5 illustrates a loud bar and a pair of mandrels being transported through the various processing stations, it is understood that a plurality of such load bars and associated mandrels are employed to provide a continuous electroforming process. More particularly, while two mandrels are positioned in juxtaposed electroforming cells during the electroforming operation which comprises a relatively longer period of time during the process, the program control **130** will be programmed for causing the transfer of other mandrels to other cells or the transfer of mandrels between the cells and the other processing stations.

An electrolytic cell constructed in accordance with features of this invention is illustrated in greater detail in FIGS. 7 through 11. Referring now to these figures, a cell is shown to comprise a rectangular shaped tank or compartment which is fabricated of double welded steel plate **200** and is lined on inner surfaces thereof with white hard rubber **202** for protecting the steel plate from the electroplating solution used therein. The exterior of the tank is sprayed with a rust inhibitor or plastic material such as a plastisol of about .03 inch thickness. A rotary drive means **204** is centrally mounted in the cell and includes a mandrel supporting drive hub **206** (FIG. 10). The rotary drive **204** further includes a thick walled, vertically orientated, generally cylindrically shaped housing **208**. The housing **204** is overcoated with a layer **211** of a material such as hard rubber which does not react with a plating solution employed with the cell. A rotary drive shaft **209** is located within a housing and is positioned in a first bearing assembly **212** which is press fitted in a sleeve **214**, and, in a second bearing assembly **210** which is positioned with an opposite end of the housing and which extends partly through an aperture in a bottom plate **224** of the tank. The hub **206** is press fitted to the upper extremity of the shaft **209** and is locked thereon by a cap and bolt assembly **216**. The hub **210** includes an integral skirt segment **218** which together with a demountable collar **220** is positioned about the upper portions of the support body **204** and functions as a splash guard for preventing entry of electroplating solution into the housing. A packing material **222** such as a lubricating grease is also provided for inhibiting the passage of electroplating which may have passed into the housing from passing to the bearing **212**. The rotary drive housing is securely mounted to the bottom steel plate **224** of the cell by bolts **226** which engage threaded apertures in this housing. A spacer **228** is positioned near a lower segment of the drive shaft **209** for spacing a drive pulley **230**. The pulley is rotated by belt **232** which extends between the pulley **230** and pulley **234** on the drive shaft **236** of an electric drive motor **238** (FIG. 8). Upon exemtation of the drive motor **238**, as indicated hereinbefore, the drive shaft **209** and the hub **206** will rotate. An annular segment **248** of hanger **234** frictionally engages a ridge **246** of the hub and rotation of the hub causes rotation of the mandrel hanger and mandrel.

In addition to providing a rotating drive for the hub **206** and a mandrel supported thereon, the drive shaft **209** also provides a low resistance conductive element for conducting a relatively high amperage electrical current between the mandrel and a power supply. A slip ring assembly **242** is provided and is supported from a lower end of drive shaft **209**. The cell during the electroplating process is adapted to draw for example a peak current on the order of 3000 amps DC at a potential of about 24 volts. A pair of contact brushes **244** are provided for effecting a low resistance electrical contact with the slip ring assembly. The mandrel **240** effectively comprises a cathode of the cell and a series current path between the slip rings and mandrel includes the drive shaft **209**, the hub **206**, and the integral raised annular segment **246** on the hub. This segment which is formed of copper functions both to mechanically engage the lower annular shaped segment **248** of the mandrel hanger as indicated hereinbefore and additionally provides a relatively low resistance current contact with the segment **248** of the mandrel hanger. The mandrel **240** is mounted to the mandrel hanger by bolts, not illustrated. Mandrels for use with this cell are described in greater detail in the aforementioned copending U.S. patent applications. Thus, a low resistance current path is provided between the brushes **244** and the mandrel cathode.

An anode electrode for the electrolytic cell comprises an annular shaped basket **250** containing chips of a metallic donor material **251** such as nickel which replenishes the electrodeposited nickel of the plating solution. The basket **250** which when loaded has considerable weight is supported within the cell by an annular shaped basket support body **252**. This basket support body (FIGS. 7, 8 and 9) comprises an annular shaped upper plate **254**, and an annular shaped lower plate **256**. The upper plate is spaced above the lower plate by a vertical wall segment **258**, a vertical wall segment **259**, and a plurality of tubular support segments **260** which are spaced about the circumference of the support body. The basket support body further includes a plurality of ribs **262** which extend inwardly from the body and taper to an inner horizontal segment **264** (FIG. 8) which functions to support a plating solution distributor manifold or sparged **318** above the lower surface of the tank and to locate the manifold or sparger centrally about the drive shaft.

The anode basket assembly (FIGS. 8 and 11) comprises an annular shaped lower body member **270** having a rear upper extending flange segment **272** and a forward upper extending flange segment **274**. An outer annular shaped wall member **276** of the basket is formed of a perforated sheet which is welded to the lower support body **270** along the flange **272**. An inner annular shaped wall member **278** of the basket is formed of an expanded sheet which is welded to the inner side of the flange **274** along its length. The inner and outer walls are spaced apart and secured together in an upper portion of the basket by radial segments **280** which are circumferentially spaced about an upper plane of the basket and are welded to the wall members **276** and **278**. Those members which are in contact with the plating solution and the donor material are formed of a material which is substantially inert with relation to the plating solution.

During the electroforming process, a basket is filled with chips of a plating metal. The basket containing the donor material functions as an anode electrode for the electrolytic cell. A relatively high amperage current path with the basket is provided through a contact terminal **281** which is bolted to a current supply bus bar **283** and through a contact ring which extends about and is bolted to a wall extension **282**. The wall extension **282** is welded to and extends from an upper portion of the wall member **276**. The terminal **281** is welded to and forms a low resistance electrical contact with the contact ring **284**. The ring **284** is formed of a conductive material such as copper and is coated with a hard rubber substance in order to inhibit the copper from reacting with the electroforming solution.

During the electroforming process, a sludge comprising a residue of the donor metal contained in the basket is formed within the basket. It is desirable to prohibit this sludge from progressing to the rotating mandrel and affecting the quality of the electroformed endless belt. A filter comprising a fabric sheet **286** is provided and is positioned along a surface of the inner basket wall **278**. As illustrated in FIG. 11, this filter extends over the height of the inner surface **278** and is rolled over the upper edge of this surface. The filter also extends about an angled flanged segment **290** of the lower plate **270**. The fabric sheet includes a plastic or elastomeric band **291** secured along on upper edge of the fabric and a similar band **292** formed along a lower edge of the fabric. The filter will collect residue and in order to maintain the filter in a flat juxtaposed position with respect to the cell member **278**, a sheet of perforated material **294** is provided and is formed into an annular shaped body adjacent the filter fabric. This sheet **294** is secured in place by a plastic ring **296** which fits snugly about the inner lower surface of this body thereby forcing the lower surface of this body against the inner wall of the basket. The sheet **294** is secured to the inner wall at an upper edge of the basket by retaining clips **298**.

A plating solution employed with the electroforming apparatus is conveyed to each of the cells by a conduit **300** (FIGS. 7, 8 and 11) which extends over the vertical tank wall **302** and is coupled to a 90° elbow **304**. The elbow is connected to a pipe **306** which extends vertically to a lower portion of the tank and is coupled to a coupling union **308** (FIG. 9), a pipe segment **310**, and to a second 90° elbow **312**. A radially extending pipe segment **314** extends between the elbow **312** and a threaded radial segment **316** of the sparger **318**. Both the pipe segment **314** and the sparger radial segment **316** are externally threaded and are lock coupled by a lock coupling unit **320**. The sparger **318** is supported above the tank floor, as indicated hereinbefore, on a horizontal segment **264** (FIG. 8) of radial extending segments **262** from a basket support body. The sparger includes a plurality of threaded apertures formed about a circumeference on an upper surface thereof. As illustrated in FIG. 8, a pipe fitting **322** is vertically threaded into each aperture and a right angle elbow **324** is coupled to each of the pipe segments **322**. A vertical extending riser tube **326** having a plurality of apertures **327** formed therefor along its length extends vertically from each of the elbows **324** and is secured near a distal segment thereof by a clip **328** which is attached to the riser and which clips to the wall body **294**. The fittings **322** are screwed into the apertures in the sparger **318** for a number of turns and can be rotated for providing that the assembly of the fitting **322**, the elbow **324**, the riser **326** and clip **328** can be rotated away from the basket thereby facilitating replacement of the filter and removal of the basket.

A plating solution is pumped to the cells through the conduit **300** and emerges within the cell through the aperture **327** in the various upstanding riser tubes **326**. Substantial uniformity in dispersal of the plating solution throughout the bath is provided by this form of supply. The plating solution level will rise to the level of a wall **330** of the tank which is the shorter of the four tank walls. This wall **330** therefore acts as a weir and the plating solution overflows the weir into a trough **332**. The plating solution thus flows from each of the cells to the trough and to an electrolytic purification tank **336** which is described in greater detail hereinafter.

A plating solution which is utilized with an electroforming cell of the type thus far described includes relatively heavy constituents which exhibit a tendency to stratify even though the solution is circulated through the piping and riser tube arrangement described hereinbefore. These heavier constituents settle to the bottom of the tank and cause a temperature gradient across the length of the mandrel wherein the upper portions of the mandrel are maintained at relatively warmer temperatures than lower portions of the mandrel. This temperature gradient results in a non-uniform plating on the mandrel and a corresponding variation in thickness of the belt formed thereon between upper and lower sections of the mandrel. In accordance with another feature of this invention, a means is provided for reducing the temperature and solution concentration gradients resulting from this stratification. This means comprises an annular shaped baffle or shroud **340** which is positioned concentrically within the cell with respect to the drive housing. This baffle, which is positioned intermediate the anode basket wall **276** and the wall of the tank is formed of PVC, for example. The positioning of this baffle within the cell creates a fluid flow path wherein the plating solution flows vertically in different directions on opposite sides of the baffle. More particularly, and with reference to FIG. 8, the arrows shown therein indicate the direction of flow of the electroplating solution on opposite sides of the baffle. It can be seen that the solution flows in a generally downward direction in that space between the inner wall of the baffle and the mandrel while the solution flows in a generally upward direction in the space between the tank walls and the baffle. The electroplating solution flows between the baffle and the tank bottom **224** in those areas near each of the corners of the tank wherein, because of a thinner layer of hard rubber protective coating in this area, the baffle is supported out of contact with this surface. The electroplating solution which enters the cell is forced under pressure through the conduit **300** and into the cell. The solution then flows toward the bottom surface of the tank and under the baffle. The baffle functions as a flow divider causing the plating solution to flow toward the lower portion of the tank thereby inhibiting the settling and build-up of heavier portions of the solution which tend to stratify.

In a preferred embodiment of the present invention, the relatively thin, flexible electrically conductive seamless belt is formed of nickel. The donor material comprises a quantity of nickel chips which are positioned in the anode basket while the plating solution comprises an aqueous solution of nickel sulfamate. This solution may comprise the following ingredients in the following amounts: nickel sulfamate, equivalent to about 8–15 ounces of nickel per gallon; nickel chloride, up to about 3 ounces per gallon; boric acid, about 4.5 to 6 ounces per gallon; a wetting agent such as sodium lauryl sulfate of up to 0.021 ounce per gallon and a stress reducer such as sodium salt of saccharin, of up to the about 0.013 ounce per gallon. A quantity of depolarized nickel chips is provided which is sufficient to replenish the nickel extracted from the nickel sulfamate solution during the electroforming process. A particularly suitable nickel comprises a sulfur depolarized nickel. The mandred **240** comprises a cylindrically shaped hollow core member composed substantially of a material selected from the group consisting of aluminum, aluminum alloys, copper and stainless steel with a layer of chromium on the surface of the core member. The chromium layer has a thickness of between about .003 and .010 inch.

The electroplating process is effectively accomplished when the plating solution is maintained at a predetermined temperature and is substantially free from impurities which can contaminate the solution and interfere with the creation of a belt having a high degree of surface smoothness and uniformity. The temperature of the plating solution should be between about 100° and 160° F. and preferably between 135° and 160° F. Current density supplied by the DC source **154** is about 20 to 600 amperes per square foot of mandrel surface. The plating process therefore results in the dissipation of a relatively large amount of heat which undesirably increases the temperature of the plating solution to levels outside of the desired range. In order to establish and maintain the plating solution in a relatively pure state, the plating solution is recirculated through processing stations which regulate the temperature of the plating solution and remove the impurities from the solution. The plating solution which overflows the weirs of the individual cells and flows into the trough **322** (FIG. 8) flows to an electric purification tank **336** and sump **360** (FIGS. 2 and 6). The solution is pumped by means **362** to a filter **364** and to a heat exchange station and is returned in purified condition at a desired temperature to the electroplating cells. The electrolytic purification station **336** is provided for removing metallic impurities from the nickel sulfamate solution prior to filtering. A pair of corrugated stainless steel plates **368** and **370** (FIG. 2) are mounted in the tank **336** and function as cathode electrodes. Anodes are provided by a plurality of anode baskets **372** which comprise tubular shaped titanium bodies each having a fabric filter anode bag (not illustrated). A DC potential is applied between the cathodes and the anodes of the purification assembly from a source **374**. The electroforming tank **336** includes a wall **375** thereof which extends coextensively with a wall of the sump tank **360** and functions as a weir. The plating solution flows from electrolytically purification into the sump tank **360** via this weir. The plating solution which has been electrolytically purified can contain undissolved micron sized solids which must be removed prior to return to the plating cells. This plating solution is pumped from the pump tank **360** to the filter station **364** which removes particulate matter.

As indicated hereinbefore, the temperature of the plating solution should be within a desired range in order to provide a desired surface, smoothness and uniformity in the electroformed belt. The electroplating solution which flows from the cells is raised in temperature due to the flow of relatively large currents and accompanying dissipation of heat in the electroforming cell. Means are provided at the heat exchanging station for cooling the electroplating solution to a lower temperature. The heat exchanger is of conventional design and receives a coolant such as chilled water from a cooling or refrigerating system not illustrated. The electroplating solution which is cooled in the heat exchanger means **368** is successively pumped to a heating system means which provides for increasing the temperature of the cooled plating solution to within relatively close limits of a desired temperature. The heat exchanging means **370** is steam heated by steam derived from a steam generator, not illustrated. The cooling heat exchanger **368** will for example cool the relatively warm plating solution from a temperature of 150° F. or above to a temperature of about 140° F. The warming heat exchanger will heat the plating solution to a temperature of 140° F. plus or minus 2° F. In addition, the heat exchanging means **370** is provided for heating the solution to the operating temperatures on startup of the system and upon the addition of replenishment solution to the system.

The quantity of electroplating solution circulated within the closed loop described hereinbefore is maintained relatively constant. Replenishment of plating solution which is carried away by the mandrels when they are removed from the electroforming cells and solution which is lost through evaporation is provided. The solution is replenished by the automatic addition of solution from a solution storage tank **372**, by the addition of deionized water from a source **374** and by the addition of solution from a nickel rinse sump tank **376** which is discussed in greater detail hereinafter. A low solution level sensor **376** and a high solution level sensor **378** are positioned within the sump tank **360**. The low level sensor is adapted for automatically signaling a low level of electroplating solution and causing the operation of pumps **380** and **382** which pump solution from the solution storage and nickel rinse storage tanks respectively. The low level sensor **376** is provided for monitoring the level of electroplating solution in the sump **360** when the mandrels are removed from all of the electroplating cells while the high level protector **378** is provided for monitoring the solution level in the sump **360** when at least two mandrels are positioned in the two electroforming cells. Additionally, a pH detector is positioned in the sump for sensing the pH of the solution.

As indicated hereinbefore, upon the completion of the electroforming process, the two mandrels are raised by the load bar and are transported to a plating solution recovery tank **77**. The recovery tank **77** contains a diluted solution of cold water and plating solution. The mandrels dwell in this tank for a limited interval of time and are then automatically transported to the cooling tank **79** where they are positioned for an interval of time for cooling to a temperature which facilitates the removal of the electroformed belts from the mandrel. The recovery rinse tank **77** is the initial rinse station for the electroformed belt and mandrel after leaving the plating cell. At this station most of the residual plating solution is removed from the belt and from the mandrel. The time of mandrel dwell at this station is under the control of program control **130**. This tank contains deionized water which overflows into the tank from the cooling tank **79**. An overflow weir **390** is provided in this tank in order to maintain a proper rinse water level. The weir overflow is conveyed to the nickel rinse tank **376**. The contents of this tank, as indicated hereinbefore, is utilized for replenishing the plating solution within the recirculating system. The nickel rinse sump tank functions as a surge tank for collecting and storing the overflow nickel rinse water from the recovery tank **77**. This collected rinse water is pumped from the sump tank **376** to the sump tank **360** as indicated hereinbefore for replenishing the solution lost through evaporation and carry away. In this manner, the plating solution which is carried away is returned to the electroforming tank and thus completes a closed loop system for the nickel plating solution.

The cooling tank **79** contains deionized water which is chilled to about 60° F. A mandrel, which is removed from the solution recovery tank **77**, is positioned within this cooling tank and upon completion of the cold soak interval, the mandrel and electroformed belt are sprayed with deionized water from a spray ring **392** as the mandrel is being raised from the cooling tank. The added volume of water which enters the cooling tank from this spraying will overflow into the solution recovery tank when the next mandrel and belt are lowered into the cooling tank. Water contained in the cooling tank **79** is recirculated by a pump **394** through a heat exchanger for maintaining the water therein at a desired cooling temperature.

The mandrel preheating tank **75** contains a solution of nickel sulfamate at a temperature of 140° F. for preheating the mandrel prior to transport of the mandrel to an electroforming cell. This preheating step minimizes temperature variations within the electroforming cell and advantageously provides for initiation of the electroforming process when the mandrel is placed on and rotated by the rotary drive of the cell. A steam heating coil **400** is positioned in the tank for maintaining the solution at the desired temperature. Means are provided for adding water to the preheating tank which is lost through evaporation. Circulation means such as a pump or the like, not illustrated are also provided for circulating the solution within the tank and thereby maintaining the solution at a relatively uniform temperature throughout the tank.

A cooled mandrel and belt formed thereon are removed from the cooling tank **79** and transported to a parting station. The parting station is that area of the apparatus wherein the electroformed nickel belt is safely removed from the mandrel to a belt carrier **81** (FIG. 1). After the belt is placed on a carrier, it is sprayed with deionized water. The mandrel, prior to returning to the preheating tank **75** is sprayed with deionized water at the parting station. A spray ring **402** at the parting station is adapted to spray both the inside and outside surfaces of the electroformed belt with deionized water. The belt thus cleaned and supported is prepared for further processing including the formation of a barrier layer and deposition of a photoconductor material on its surface.

A process and apparatus have thus been described which advantageously provide for the efficient and relatively rapid and economic production of relatively thin, flexible, electrically conductive seamless belts. There has been described an electroplating cell and mandrel transport arrangement which provides for the unobstructed lowering of a mandrel onto a rotary drive in an electroplating bath. A hub of the drive mechanically supports, engages for rotation, and effects electrical contact with the mandrel. The process described provides for preheating the mandrel thereby enabling the initiation of the electroplating process upon lowering of the mandrel into the cell. Preheating further reduces temperatures variations which disadvantageously will result in nonuniformities in surface thickness and smoothness of the produced belt. While the belts are being electrodeposited on two mandrels in juxtaposed cells, the apparatus can efficiently operate on other mandrels at other operating stations of the apparatus for conditioning the mandrels for electroplating, for recovering plating solution, for cooling the mandrels and for facilitating removal of the belts from the mandrels. A high degree of uniformity and smoothness in the surface of the reproduced belt is provided by inhibiting the transfer of residue from a donor material to the mandrel in the cell, and by recirculating the electroplating solution in order to carefully control its temperature and remove impurities from the solution. The surface uniformity and smoothness of the reproduced belt is further enhanced by the provision of solution flow diverting means within the cell which establishes a flow path within the cell for causing the solution to carry away heavier components of the solution which exhibit a tendance to stratify, to settle in the cell and to cause undesirable temperature gradience.

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. An electrolytic cell for electroforming a relatively thin, flexible, electrically conductive endless belt comprising:

a vertically oriented upstanding rotatable spindle positioned within a tank containing a plating solution;

said spindle having an upper surface thereof adapted for receiving, mechanically engaging and forming electrical contact with a cylindrically shaped mandrel which is positioned thereon and which extends about a portion of said spindle;

an annular shaped container for a donor metal positioned concentrically with respect to said spindle in said tank;

means adapted for applying a potential of predetermined polarity from a source of DC plating potential to said container;

means for applying a potential of opposite polarity from said source of DC plating potential to said spindle for establishing said mandrel as an electrode of said cell;

means for rotating said spindle for causing the rotation of said mandrel within said solution;

means for conveying said plating solution through said cell, said conveying means including a sparger positioned near the bottom of said cell, said sparger further including a plurality of verticle upstanding tubular shaped bodies having a multiplicity of apertures formed along their length and coupled to said sparger for dispersing said plating solution;

means to control the temperature of the plating solution within a relatively narrow predetermined temperature range;

automatic sensor means for activating pumps which replenish the plating solution during an electroforming process; and, means for automatically raising and lowering the mandrel into and out of said cell including an overhead hoist and transfer means.

2. The electrolytic cell of claim **1** including means for suppling a plating solution to said tank.

3. The electrolytic cell of claim **1** wherein said spindle includes a drive shaft extending through a bottom plate of said tank and means are coupled to an extending segment of said drive shaft for rotating said spindle.

4. The apparatus of claim **3** wherein means are provided for coupling said source of potential to said rotating shaft.

5. The apparatus of claim **1** wherein said container for donor material comprises a basket having annular shaped vertically orientated wall members, said wall members having perforations therein for permitting the flow of plating solution through said basket.

6. The apparatus of claim **1** including an annular shaped support body positioned on a bottom plate of said tank for supporting said container of donor material above said bottom plate.

7. The apparatus of claim **5** including a solution permeable filter positioned along a surface of said inner wall member for restricting the flow of contaminants through said filter.

8. The apparatus of claim **7** wherein said filtering means comprises a sheet of fabric and an apertured sheet of metal is provided and sandwiches said fabric between said inner wall member and said sheet for supporting said fabric in a flat configuration against an inner wall member of said basket.

9. The apparatus of claim **8** including an expansible annular shaped mounting member positioned against said perforated filter support sheet for forcing said support sheet against said inner wall member.

10. The apparatus of claim **9** including clip means for securing said perforated sheets to said inner wall member.

11. The apparatus of claim **1** wherein said upstanding tubes include means for altering the location of said tubes.

12. The apparatus of claim **1** including means for directing plating solution flow through said tank thereby reducing the stratification of components in said plating solution, wherein a flow dividing means comprises an annular shape wall body is positioned between the wall members of said tank and said donor material container extending in a vertical direction from a floor member of said tank to a location above the level of the plating solution in said tank, said flow dividing means providing a flow near the lower portion of said tank.

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