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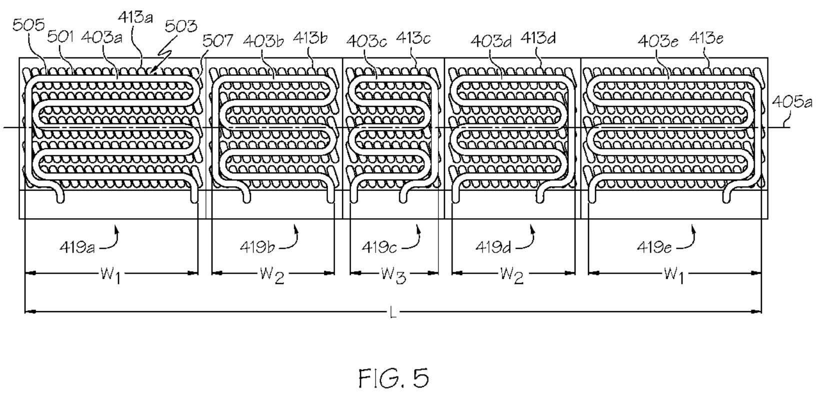


FIG. 5

(57) Abstract: Apparatus for producing glass ribbon comprises a plurality of cooling coils positioned along a cooling axis of the apparatus extending transverse to a draw direction. The cooling coils are configured to control a transverse temperature profile of the glass ribbon along a cooling axis. Each cooling coil can be fabricated from at least one tube and configured to circulate fluid to remove heat from the cooling coil. In further examples, methods of producing a glass ribbon include the step of controlling a transverse temperature profile of the glass ribbon along a width of the glass ribbon. The step of controlling the temperature profile includes selectively removing heat from at least one of a plurality of cooling coils positioned along the cooling axis.

WO 2012/174353 A2

APPARATUS AND METHODS FOR PRODUCING A GLASS RIBBON

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority under 35 U.S.C. § 120 of U.S. Application Serial No. 13/163,176 filed on June 17, 2011, the content of which is hereby incorporated by reference.

FIELD

[0002] The present invention relates generally to apparatus and methods for producing glass ribbon and, more particularly, to apparatus and methods for producing a glass ribbon with a plurality of cooling coils extending along a cooling axis that is transverse to a draw direction of the glass ribbon.

BACKGROUND

[0003] It is known to draw a glass ribbon with a draw device. The glass ribbon may be subsequently divided to produce a plurality of glass sheets that may be employed in a wide range of applications. The glass ribbon is known to be drawn in a viscous state for eventual cooling into an elastic state where final features are permanently set into the glass sheet.

SUMMARY

[0004] The following presents a simplified summary of the disclosure in order to provide a basic understanding of some example aspects described in the detailed description.

[0005] In one example aspect, an apparatus for producing glass ribbon comprises a drawing device configured to draw molten glass into a glass ribbon in a draw direction along a draw plane of the apparatus. The apparatus further includes a cooling apparatus including a plurality of cooling coils positioned along a cooling axis of the apparatus extending transverse to the draw direction. The cooling coils are configured to control a transverse temperature profile of the glass ribbon along the cooling axis. Each cooling coil is fabricated from at least one tube and configured to circulate fluid through the at least one tube to remove heat from the cooling coil.

[0006] In another example aspect, a method of producing a glass ribbon includes the step of drawing molten glass in a draw direction into a viscous zone to form a glass ribbon including opposed edges extending in the draw direction. The opposed edges are spaced apart along a width of the glass ribbon that is transverse to the draw direction. The method further includes the step of drawing the molten glass from the viscous zone into a setting zone downstream from the viscous zone, wherein the glass ribbon is set from a viscous state to an elastic state. The method further includes the step of drawing the glass ribbon into an elastic zone downstream from the setting zone. The apparatus also includes the step of controlling a transverse temperature profile of the glass ribbon along the width of the glass ribbon in at least one of the viscous zone, the setting zone and the elastic zone. The step of controlling the temperature profile includes selectively removing heat from at least one of a plurality of cooling coils positioned along a cooling axis that is transverse to the draw direction.

Brief Description Of The Drawings

[0007] These and other features, aspects and advantages of the present disclosure are better understood when the following detailed description is read with reference to the accompanying drawings, in which:

[0008] **FIG. 1** is a schematic illustration of an example fusion draw apparatus including a cooling apparatus in accordance with aspects of the disclosure;

[0009] **FIG. 2** illustrates a sectional view of a forming vessel of the fusion draw apparatus of **FIG. 1**;

[0010] **FIG. 3** schematically illustrates a glass ribbon being drawn off the forming vessel of **FIG. 1**;

[0011] **FIG. 4** illustrates a cooling apparatus in accordance with one example aspect of the disclosure;

[0012] **FIG. 5** is a cross-sectional view along line 5-5 of **FIG. 4**, illustrating features of the cooling apparatus of **FIG. 4**;

[0013] **FIG. 6** is a cross-sectional view along line 6-6 of **FIG. 4**, illustrating features of the cooling apparatus of **FIG. 4**; and

[0014] **FIG. 7** illustrates a method of replacing a control module of the cooling apparatus with a new control module.

DETAILED DESCRIPTION

[0015] Methods will now be described more fully hereinafter with reference to the accompanying drawings in which example embodiments of the disclosure are shown. Whenever possible, the same reference numerals are used throughout the drawings to refer to the same or like parts. However, this disclosure may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein.

[0016] Apparatus can be provided to form a glass ribbon for subsequent processing into glass sheets. **FIG. 1** schematically illustrates a fusion draw apparatus **101** although up draw, slot draw or other glass forming techniques may be used with aspects of the disclosure in further examples. With such fusion draw process techniques, the present disclosure provides for control of viscosity and temperature cooling curves to provide process stability and facilitate quality performance. For instance, proper cooling below a forming vessel can help provide the glass ribbon with sufficient cooling and high-enough viscosity to minimize ribbon bagginess, i.e., the tendency of the ribbon to deform uncontrollably, such as unevenly under its own weight. Proper cooling below the forming vessel can also help stabilize thickness and provide shape control. Furthermore, proper cooling can help provide proper transitioning and conditioning of the glass into the visco-elastic region where final glass flatness, stress, and shape is controlled.

[0017] As illustrated, the fusion draw apparatus **101** can include a melting vessel **105** configured to receive batch material **107** from a storage bin **109**. The batch material **107** can be introduced by a batch delivery device **111** powered by a motor **113**. An optional controller **115** can be configured to activate the motor **113** to introduce a desired amount of batch material **107** into the melting vessel **105**, as indicated by arrow **117**. A metal probe **119** can be used to measure a glass melt **121** level within a standpipe **123** and communicate the measured information to the controller **115** by way of a communication line **125**.

[0018] The fusion draw apparatus **101** can also include a fining vessel **127**, such as a fining tube, located downstream from the melting vessel **105** and coupled to the melting vessel **105** by way of a first connecting tube **129**. A mixing vessel **131** such as a stir chamber, can also be located downstream from the fining vessel **127** and a delivery vessel **133** may be located downstream from the mixing vessel **131**. As shown, a second connecting tube **135** can couple the fining vessel **127** to the mixing vessel **131** and a third connecting tube **137** can couple the mixing vessel **131** to the delivery vessel **133**. As further illustrated, a downcomer **139** can be positioned to deliver glass melt **121** from the delivery vessel **133** to a fusion draw machine **140**. The fusion draw machine **140** can include the a forming vessel **143** provided with an inlet **141** to receive glass melt from the downcomer **139**.

[0019] As shown, the melting vessel **105**, fining vessel **127**, the mixing vessel **131**, delivery vessel **133**, and forming vessel **143** are examples of glass melt stations that may be located in series along the fusion draw apparatus **101**.

[0020] The melting vessel **105** is typically made from a refractory material, such as refractory (e.g. ceramic) brick. The fusion draw apparatus **101** may further include components that are typically made from platinum or platinum-containing metals such as platinum-rhodium, platinum-iridium and combinations thereof, but which may also comprise such refractory metals such as molybdenum, palladium, rhenium, tantalum, titanium, tungsten, ruthenium, osmium, zirconium, and alloys thereof and/or zirconium dioxide. The platinum-containing components can include one or more of the first connecting tube **129**, the fining vessel **127** (e.g., finer tube), the second connecting tube **135**, the standpipe **123**, the mixing vessel **131** (e.g., a stir chamber), the third connecting tube **137**, the delivery vessel **133** (e.g., a bowl), the downcomer **139** and the inlet **141**. The forming vessel **143** is also made from a refractory material and is designed to form the glass ribbon **103**.

[0021] FIG. 2 is a cross-sectional perspective view of the fusion draw apparatus **101** along line 2-2 of **FIG. 1**. As shown, the forming vessel **143** includes a forming wedge **201** comprising a pair of downwardly inclined forming surface portions **203**, **205** extending between opposed ends of the forming wedge **201**. The pair of downwardly inclined forming surface portions **203**, **205** converge along a draw direction **207** to form a root **209**. A draw plane **211** extends through the root **209** wherein the glass ribbon **103** may be drawn in the draw direction **207** along the draw plane **211**. As shown, the draw plane **211** can bisect the root **209** although the draw plane **211** may extend at other orientations with respect to the root **209**.

[0022] The fusion draw apparatus **101** for fusion drawing a glass ribbon can also include at least one edge roller assembly including a pair of edge rollers configured to engage a corresponding edge **103a**, **103b** of the glass ribbon **103** as the ribbon is drawn off the root **209** of the forming wedge **201**. The pair of edge rollers facilitates proper finishing of the edges of the glass ribbon. Edge roller finishing provides desired edge characteristics and proper fusion of the edge portions of the molten glass being pulled off opposed surfaces of an edge director **212** associated with the pair of downwardly inclined forming surface portions **203**, **205**. As shown in **FIG. 2**, a first edge roller assembly **213a** is associated with the first edge **103a**. **FIG. 3** shows a second edge roller assembly **213b** associated with the second edge **103b** of the glass ribbon **103**. Each edge roller assembly **213a**, **213b** can be substantially identical to one another although the pairs of edge rollers may have different characteristics in further examples.

[0023] As shown in **FIG. 3**, the fusion draw apparatus **101** can further include a first and second pull roll assembly **301a**, **301b** for each respective edge **103a**, **103b** to facilitate pulling of the glass ribbon **103** in the draw direction **207** of the draw plane **211**.

[0024] The fusion draw apparatus **101** can further include a cutting device **303** that allows the glass ribbon **103** to be cut into distinct glass sheets **305**. The glass sheets **305** may be subdivided into individual glass sheets for incorporating in the various display devices, such as a liquid crystal display (LCD). Cutting devices may include laser devices, mechanical scoring devices, traveling anvil machines and/or other devices configured to cut the glass ribbon **103** into the distinct glass sheets **305**.

[0025] Referring to **FIG. 2**, in one example, the glass melt **121** can flow into a trough **215** of the forming vessel **143**. The glass melt **121** can then simultaneously flow over corresponding weirs **217a**, **217b** and downward over the outer surfaces **219a**, **219b** of the corresponding weirs **217a**, **217b**. Respective streams of glass melt then converge along the downwardly inclined forming surface portions **203**, **205** to the root **209** of the forming vessel **143**. A glass ribbon **103** is then drawn off the root **209** in the draw plane **211** along draw direction **207**.

[0026] Turning to **FIG. 3**, the glass ribbon **103** is drawn from the root **209** in the draw direction **207** of the draw plane **211** from a viscous zone **307** to a setting zone **309**. In the setting zone **309**, the glass ribbon **103** is set from a viscous state to an elastic state with the desired cross-sectional profile. The glass ribbon is then drawn from the setting zone **309** to an elastic zone **311**. In the elastic zone **311**, the profile of the glass ribbon from the viscous zone **307** is frozen as a characteristic of the glass ribbon. While the set ribbon may be flexed away from this configuration, internal stresses can cause the glass ribbon to bias back to the original set profile.

[0027] Any of the apparatus for producing glass ribbon can include a cooling apparatus configured to control a transverse temperature profile of the glass ribbon along a cooling axis. For example, the fusion draw apparatus **101** is illustrated as including a cooling apparatus. **FIG. 4** illustrates one example cooling apparatus **401** in accordance with aspects of the disclosure although other cooling apparatus configurations may be provided in further examples. The cooling apparatus **401**, for example, may be part of the fusion draw machine **140** that has been schematically represented in **FIGS. 1-3**. The details of the cooling apparatus **401** are not illustrated in **FIGS. 1-3** for clarity but aspects of an example cooling apparatus **401** is more fully shown in **FIGS. 4-7**.

[0028] FIGS. 4-7 illustrate an example apparatus for producing glass ribbon that may comprise the illustrated fusion draw apparatus **101,** although up draw or other glass forming apparatus may also be provided with a cooling apparatus in accordance with aspects of the disclosure. As shown in **FIGS. 4-6**, the illustrated cooling apparatus **401** can include a plurality of cooling coils **403a-e** positioned along a cooling axis **405a** of the fusion draw apparatus **101**. As illustrated, the cooling axis **405a** can be designed to extend transverse, such as substantially perpendicular, to the draw direction **207**. For example, as shown in **FIG. 3**, the cooling axis **405a** can be substantially perpendicular to the draw direction **207** while being positioned in an upper portion of the setting zone **309** where the glass ribbon **103** begins to transition from a viscous state to an elastic state. As shown in **FIG. 4**, in such a position a heat shield **406** may be provided to protect structures of the fusion draw machine **140**. The heat shield **406** can comprise a SiC material although other materials may be used in further examples.

[0029] In addition or alternatively, as shown in **FIGS. 3 and 4**, the cooling axis **405b** may be located in a lower portion of the setting zone **309** where the glass ribbon **103** finalizes the transition from the viscous state to an elastic state. Still further, as shown schematically in **FIG. 3**, the cooling axis **405c** may be located in the elastic zone **311** where the glass ribbon is fully set in the elastic state. In fact, it will be appreciated that the cooling axis can be located at various positions of the glass ribbon traveling from the forming vessel **143**. For instance, in the illustrated example, the cooling axis may be located at various alternative positions of the glass ribbon between the root **209** of the forming wedge **201** and the cutting device **303**.

[0030] Providing a cooling axis may be beneficial to help control a transverse temperature profile of the glass ribbon **103** along the cooling axis. For example, the transverse temperature profile can be located substantially along a profile axis of the glass ribbon. **FIG. 4** illustrates an example where a temperature profile axis **407a** of the glass ribbon **103** is substantially perpendicular to the draw direction **207** and parallel to the corresponding cooling axis **405a**. Likewise, another temperature profile axis **407b** of the glass ribbon **103** is substantially perpendicular to the draw direction **207** and parallel to the corresponding cooling axis **405b**. As such, it will be appreciated that the profile axis (e.g., **407a and 407b**) may be substantially perpendicular to the draw direction **207** and likewise substantially perpendicular to the elongated axis of the glass ribbon. Still further the profile axis may be substantially perpendicular to the edges **103a**, **103b** of the glass ribbon although the profile axis may be oriented at an oblique angle with respect to the edges **103a**, **103b** and/or the draw direction **207**.

[0031] As such, apparatus and methods of the present disclosure can facilitate control of the transverse temperature of the glass ribbon **103** along the cooling axis at various locations along the draw direction **207** of the glass ribbon **103**. Allowing control of the transverse temperature of the glass ribbon can facilitate control of the transverse viscosity and/or temperature cooling curves in a transverse direction of the glass ribbon **103**.

[0032] The plurality of cooling coils **403a-e** referenced in **FIG. 4** is illustrated in **FIGS. 5-6**. **FIG. 5** is a cross-sectional view of portions of the fusion draw machine **140** along line 5-5 of **FIG. 3**. For illustrative purposed, **FIG. 5** shows a plurality of cooling coils **403a-e** including five cooling coils **403a-e** although more or less cooling coils may be provided in further examples.

[0033] Each cooling coil can be fabricated from at least one tube and configured to circulate fluid through the at least one tube to remove heat from the cooling coil. As such, liquid and/or gas cooling fluid may be used to circulate through the tube without physically contacting the glass ribbon or other portions of the fusion draw apparatus **101**. In one example, the tube can be configured to circulate liquid to increase the rate at which heat transfer is removed from the respective cooling zone. As such, the at least one tube can move liquid into the vicinity of the cooling zone without contaminating electrical components or other structures of the fusion draw machine. Thus, the benefits of high heat transfer associated with liquid cooling with a cooling coil including at least one tube can be achieved without contacting the other portions of the apparatus.

[0034] In one example, the at least one cooling coil can include a plurality of cooling coils or segments of coils that are joined together. In further examples, one or more of the coils may be formed with a seam, either at the interfaces between the segments and/or along a longitudinal axis of the cooling tubes. For example, a plurality of straight segments may be welded, soldered, or otherwise joined together with a plurality of elbow or U-shaped segments. Alternatively, as shown in **FIG. 5**, the at least one tube of each cooling coil can comprise a single substantially continuous tube **501** that is bent into a compact shape **503**. The single substantially continuous tube **501** can be provided without any weld or solder seams along a compact shape **503** of the cooling coil (e.g., along a longitudinal axis of a cooling tube) although the compact shape **503** may be provided by more than one tube and/or a tube with seams. However, providing the cooling coil with the illustrated single continuous tube without seams can reduce the probability of cracks, fluid leaks and/or catastrophic failure of the cooling coil that may otherwise damage electrical and other components of the apparatus in the vicinity of the cooling coils.

[0035] Various compact shapes may be used in accordance with aspects of the disclosure. For example, as shown in **FIG. 5**, the compact shape **503** can include a serpentine shape. The serpentine shape can allow the at least one tube to achieve a compact form to increase the surface area of the cooling coil within the corresponding cooling zone. For instance, as shown in **FIG. 5**, the serpentine shape can include a plurality of straight segments **505** joined together at bent ends **507**.

[0036] As shown in **FIG. 4**, the compact shape **503** of each of the cooling coils **403a-e** can extend along a cooling plane **411**. In such a configuration, the serpentine shape can substantially extend along the cooling plane **411** such that the straight segments **505** and bent ends **507** are substantially coplanar with one another. In such an example, relatively consistent cooling can be achieved above and below the temperature profile axis **407a**, **407b**. As further illustrated, the cooling plane **411** faces the draw plane **211**. In one example, the cooling plane **411** can be positioned at an angle to the draw plane **211** to allow a change in heat transfer along a height of the cooling coils **403a-e**. Alternatively, as shown, the cooling plane **411** can be substantially parallel to the draw plane **211**. Providing a substantially parallel relative orientation can help evenly draw heat from the glass ribbon to facilitate maintenance of a desired temperature profile over the height of the cooling zone along the draw direction **207**.

[0037] Referring to **FIG. 5**, the plurality of cooling coils **403a-e** can be aligned relative to one another in a row of cooling coils **403a-e** extending along the cooling axis **405a**. Although a single row is shown, further examples may include cooling coils arranged in an array of cooling coils having multiple rows. In such examples, the cooling coils may also be aligned along respective columns to form a matrix of cooling coils.

[0038] As further illustrated, the plurality of cooling coils **403a-e** can each include a corresponding transverse width "$\mathbf{W_1}$", "$\mathbf{W_2}$" and "$\mathbf{W_3}$" extending along the cooling axis of the apparatus. As shown, the transverse width of at least one of the plurality of cooling coils is greater than the transverse width of another of the plurality of cooling coils. For example, the center of the glass ribbon may be associated with one or more cooling coils that have a smaller transverse width than the outer cooling coils. For instance, by way of illustration, the row of cooling coils **403a-e** can include the illustrated inner cooling coil **403c** with a transverse width "$\mathbf{W_3}$" that is less than the transverse width "$\mathbf{W_2}$" of an inner pair of cooling coils **403b**, **403d** straddling the inner cooling coil **403c**. Likewise, the row of cooling coils **403a-e** can include an outer pair of cooling coils **403a**, **403e** with a width "$\mathbf{W_1}$" that can be greater than the width "$\mathbf{W_2}$" of the inner pair of cooling coils **403b**, **403d** and the width "$\mathbf{W_3}$" inner cooling coil **403c**.

[0039] In further examples, one or more of the cooling coils may include the same width. For example as shown, the inner pair of cooling coils **403b**, **403d** have the same transverse width "$\mathbf{W_2}$" and the outer pair of cooling coils **403a**, **403e** has the same transverse width "$\mathbf{W_1}$". Providing cooling coils with different and/or the same width can help compensate cooling and/or heating of the glass ribbon **103** at different distances from the center of the glass ribbon. Moreover, the cooling coils may have a different width to correspond to the transverse width of a plurality of heating devices described more fully below.

[0040] As shown in **FIG. 6**, each transverse width "W_1", "W_2" and "W_3" of the plurality of cooling coils **403a-e** is substantially less than a draw width "W_d" of the fusion draw apparatus **101**. As shown in **FIG. 6**, the fusion draw width "W_d" can be considered a transverse width of the glass ribbon **103** along a direction perpendicular to the draw direction **207** between the edges **103a**, **103b**. Providing each cooling coil **403a-e** with transverse widths "W_1", "W_2" and "W_3" that are substantially less than the draw width "W_d" of the fusion draw apparatus **101** can allow selective cooling within cooling zones **601a-e** to help achieve the desired temperature profile along the cooling axis **405a**.

[0041] The row of cooling coils **403a-e** can also be aligned relative to one another in a row of cooling coils **403a-e** along the cooling axis **405a** such that an overall length "**L**" of the cooling coils is greater than or about equal to the draw width "W_d" of the fusion draw apparatus **101**. While smaller lengths are possible, providing the length "**L**" greater than or about equal to the draw width "W_d" can allow transverse temperature profile control across the entire width of the glass ribbon **103**.

[0042] As shown in **FIG. 6**, each of the cooling coils **403a-e** can be independently operable from the other cooling coils. For example, each of the plurality of cooling coils **403a-e** can include a respective inlet **603a-e** configured to receive a cooling fluid such as a gas and/or liquid. For example, as shown, each respective inlet **603a-e** can be provided with a cooling liquid **607**, such as water, from a source **609** of cooling liquid **607**. Each of the cooling coils **403a-e** can also include a respective outlet **605a-e** configured to pass heated liquid from the cooling coil to a containment structure **611**, although a closed liquid circuit arrangement may be provided in further examples. In such examples, a heat exchanger can be used to remove heat from the heated fluid before reintroducing the cooled fluid back into the respective inlet **603a-e**.

[0043] In one example, a pump **613** may be provided to pump liquid to the respective inlets **603a-e** to be circulated through the cooling coils **403a-e**. In one example, a manifold **615** may be provided with a plurality of solenoid flow valves **617** that may be manually or automatically operated to adjust the flow rate of fluid through the respective cooling coil **403a-e**. In one example, a computer controller **619** may be provided to send signals along a respective line **621** to the respective solenoid flow valve **617**. In further examples, a predetermined flow for each respective cooling coil **403a-e** may be programmed into the computer or calculated by the computer by further inputs. In one example, a flow sensor **623** can monitor the fluid flow within each cooling coil **403a-e** and provide a signal by way of a respective communication line **625** to the computer controller **619**. As such, the actual fluid flow through each respective cooling coil **403a-e** can be monitored by the respective flow sensor **623**. The fluid flow signal can then be provided to the computer controller **619** that can then output a command signal to operate the pump **613** and adjust the respective solenoid flow valve **617** to provide the appropriate flow rate through the corresponding cooling coil **403a-e**. Although not shown, each fluid circuit may include a pressure relief valve although not required in further examples.

[0044] As further shown in **FIG. 6**, each of the inlets **603a-e** may be provided with a corresponding inlet temperature sensor $\mathbf{T_1}$ and each of the outlets **605a-e** may be provided with a corresponding outlet temperature sensor $\mathbf{T_2}$. As such, the inlet and outlet temperatures of the fluid entering and exiting each of the cooling coils **403a-e** may be monitored. The computer controller **619** can be programmed to calculate the change in temperature (i.e., $\mathbf{\Delta T}$) measured by the temperature sensors $\mathbf{T_1}$, $\mathbf{T_2}$. Moreover, the computer controller **619** can be programmed with the specific heat of the fluid being circulated through the cooling coils **403a-e**. Together with the flow rate of the fluid measured by the flow sensors **623**, the computer controller **619** may approximate the heat being removed by each cooling coil **403a-e**. This information may be further used to help optimize the temperature control within the cooling zones **601a-e**.

[0045] In further examples, the apparatus can include a plurality of heat sensors **627** associated with each of the cooling zones **601a-e**. The heat sensors **627** can be configured to monitor the temperature of the glass ribbon at different positions along the transverse profile. In one example, each heat sensor **627** can include a communication line **629** configured to allow a signal corresponding to the sensed temperature to be transmitted back to the computer controller **619**. As such, a temperature of the portion of the glass ribbon **103** associated with each cooling zone **601a-e** may monitored. Based on the sensed temperature, the flow of fluid through each cooling coil **403a-e** may be independently operated from the other cooling coils to achieve a desired transverse temperature profile of the glass ribbon **103** along the cooling axis **405a**. As such, the illustrated configuration provides a control system configured to selectively operate the cooling coils based on corresponding temperatures sensed at different positions along the transverse profile.

[0046] As shown in **FIGS. 4-7**, the fusion draw apparatus **101** may also optionally include a plurality of heating devices **413a-e** positioned along the cooling axis **405a**. Various heating devices may be used in accordance with aspects of the disclosure. For example, as shown in **FIG. 4**, the heating devices **413a-e** can include rows of heating elements **415** that may be electrically arranged in parallel or series with respect to one another. Each row of heating elements **415** can be designed to achieve different temperatures to allow production of a temperature gradient in the draw direction **207**. In further examples, each row of heating elements **415** can be designed to achieve substantially the same temperature to expose a portion of the ribbon to substantially the same heated temperature as the portion of the glass passes by the heating devices **413a-e**.

[0047] As also shown in **FIG. 4**, the heating elements **415** can each extend along a heating plane **417**. In one example, the heating plane **417** is positioned at an angle to the draw plane **211** and/or the cooling plane **411** to allow a change in heat transfer as a portion of the glass ribbon **103** passes by the heating plane **417**. Alternatively, as shown, the heating plane **417** can be substantially parallel to the cooling plane **411** and the draw plane **211** although the heating plane **417** may only be substantially parallel with the cooling plane **411** or the draw plane **211** in further examples. Providing a substantially parallel relative orientation can help evenly apply heat to the glass ribbon to facilitate maintenance of a desired temperature profile over the height of the cooling zone (or heat zone) along the draw direction **207**.

[0048] Referring to **FIG. 5**, the plurality of heating devices **413a-e** can be aligned relative to one another in a row of heating devices **413a-e** also extending along the cooling axis **405a** together with the row of cooling coils **403a-e**. Although a single row is shown, further examples may include heating devices arranged in an array of heating devices having multiple rows. In such examples, the heating devices may also be aligned along respective columns to form a matrix of cooling coils.

[0049] As further illustrated, the plurality of heating devices **413a-e** can also include a corresponding transverse width that may be about equal to a corresponding one of the cooling coils **403a-e**. As such, as shown in **FIG. 5**, each of the heating devices can include a transverse width that is substantially equal to the transverse width "$\mathbf{W_1}$", "$\mathbf{W_2}$" and "$\mathbf{W_3}$" of the corresponding cooling coil. As described with the cooling coils above, the heating devices may likewise have the same or different widths. Providing heating devices with the same and/or different widths can help compensate for faster cooling that typically occurs towards the edges **103a, 103b** of the glass ribbon **103**.

[0050] As shown in **FIG. 6**, each transverse width "$\mathbf{W_1}$", "$\mathbf{W_2}$" and "$\mathbf{W_3}$" also corresponding to the widths of the heating devices **413a-e** is likewise substantially less than a draw width "$\mathbf{W_d}$" of the fusion draw apparatus **101**. Providing each of the heating devices **413a-e** with a corresponding transverse width "$\mathbf{W_1}$", "$\mathbf{W_2}$" and "$\mathbf{W_3}$" that is substantially less than the draw width "$\mathbf{W_d}$" of the fusion draw apparatus **101** can allow selective heating within cooling zones **601a-e** to help achieve the desired temperature profile along the cooling axis **405a**. The row of heating devices **413a-e** can also be aligned relative to one another in a row of heating devices **413a-e** along the cooling axis **405a** such that a length "**L**" is greater than or about equal to the draw width "$\mathbf{W_d}$" of the fusion draw apparatus **101**. While smaller lengths are possible, providing the length "**L**" greater than or about equal to the draw width "$\mathbf{W_d}$" can allow transverse temperature profile control across the entire width of the glass ribbon **103**.

[0051] As shown in **FIG. 6**, each of the heating devices **413a-e** can be independently operable from the other heating devices. For example, each of the plurality of heating devices **413a-e** can include electrical contacts **631a, 631b** configured to be placed in an electrical circuit to allow heating of the windings of the heating device when running electrical current through the windings. In one example, an electrical relay **633** is configured to receive signals from the computer controller **619** to individually control the current flowing through the electrical contacts **631a, 631b** depending on the desired heat output determined desirable at each cooling zone **601a-e**. In further examples, a predetermined electrical current for each one of the respective heating devices **413a-e** may be programmed into the computer controller or calculated by the computer controller by further inputs.

[0052] In still further examples, electrical current flow through each of the heating devices **413a-e** can be independently operated based on the sensed temperature from the plurality of optional heat sensors **627**. As such, the illustrated apparatus provides a control system configured to selectively operate the heating devices based on corresponding temperatures sensed at different positions along the transverse profile.

[0053] In further examples, one or more of the cooling coils **403a-e** may be associated with each of the heating devices **413a-e**. Alternatively, one or more of the heating devices **413a-e** may be associated with each of the cooling coils **403a-e**. As shown in **FIGS. 5-6**, each of the plurality of heating devices **413a-e** may be associated with a corresponding one of the cooling coils **403a-e**. In some examples, the heating devices **413a-e** may be operated at the same time as the cooling coils **403a-e**. As such, fine tune adjustment of cooling within each respective cooling zone **601a-e** may be provided by operating the heating device together with the respective cooling device. Alternatively, the cooling coils **403a-e** may be turned off wherein cooling is carried out by only operating the heating devices that control the temperature profile. In such examples, the at least one tube of the cooling coil may comprise a wide range of materials capable of withstanding high temperatures when only operating the heating devices. For example, the at least one tube can comprise a high nickel alloy, 310 stainless steel or other high temperature materials.

[0054] Still further, it is contemplated that the cooling coils may optionally be provided with a coating to obtain a desired emissivity of the material to thereby impact radiation heat loss from the glass ribbon. In addition or alternatively, the same or a different coating may also be provided to inhibit corrosion. As such, one or more coatings may be applied to the cooling coils to enhance emissivity characteristics and/or enhance corrosion resistance.

[0055] As shown schematically in **FIGS. 4 and 7**, the fusion draw apparatus **101** can include a plurality of temperature control modules **419a-e** positioned along the cooling axis **405a** of the fusion draw apparatus **101**, wherein each of the control modules **419a-e** includes at least one of the plurality of cooling coils **403a-e** and at least one of the plurality of heating devices **413a-e**. As shown in **FIG. 4**, each temperature control module **419a-e** can be mounted with respect to the draw device, such as the illustrated forming wedge **201**, such that the corresponding cooling coil **403a-e** is positioned between the corresponding heating device **413a-e** and the draw plane **211** of the fusion draw apparatus **101**.

[0056] Still further, as shown in **FIGS. 4 and 7**, each temperature control module **419a-e** may be removably mounted with respect to the draw device although nonremovable mounting configurations may be used in further examples. For example, as schematically shown in **FIG. 4**, a mounting bracket **421** can be removably mounted by way of fasteners **423** to a support structure **425** of the fusion draw apparatus **101**. Another set of fasteners **427** can attach the heating devices **413a-e** to the mounting bracket **421**. Yet another set of fasteners **429** can attach the cooling coils **403a-e** to the mounting bracket **421**. As shown, the tube **501** can include a mounting segment **431** that may be received within a mounting groove **433** formed in an insulating brick **435** associated with the corresponding heating device **413a-e**. As shown, the mounting groove **433** can receive a corresponding mounting segment **431** of the tube **501** to help provide a secure mounting of the compact shape **503** of the cooling coil **403a-e** in a cantilever fashion with respect to the insulating brick **435**. Although not shown, further optional mounting structures may be provided in accordance with further aspects of the disclosure.

[0057] As shown, the mounting bracket **421** provides for removable mounting of the temperature control module **419a-e** with respect to the draw device. For example, as shown in **FIG. 7**, a selected one of the temperature control modules **419a-e** may be removed by unfastening mounting fasteners **423** corresponding to the selected control module. As shown by the arrow **701**, the old control module **703** may be quickly removed and replaced by a new control module **705**. As such, a selected control module may be quickly replaced without the need to replace the other control modules. Furthermore, it is possible to replace a damaged heating device and/or cooling coil associated with the old control module **703** while drawing molten glass in the draw direction and without shutting down the fusion draw process. The old control module can then be refurbished to provide for another replacement module in the future.

[0058] As discussed previously, the cooling coil and/or heating device may be provided at various locations. As shown in **FIG. 4**, another temperature control module **437a-e** may be provided along the cooling axis **405b** located in the lower portion of the setting zone **309**. The temperature control modules **437a-e** may be substantially identical to the control modules **419a-e** described above. Alternatively, as shown, the temperature control modules **437a-e** may be a different size than the control modules **419a-e**. In still further examples, only a cooling device or heating device may be provided along the cooling axis **405b** in further examples.

[0059] In operation, methods of producing a glass ribbon **103** can include the steps of drawing molten glass in the draw direction **207** into the viscous zone **307** to form the glass ribbon **103** including the opposed edges **103a**, **103b** extending in the draw direction **207**. As shown in **FIGS. 1 and 3**, the opposed edges **103a**, **103b** are spaced apart along the width of the glass ribbon **103** that is transverse to the draw direction **207**.

[0060] The method then includes the step of drawing the molten glass from the viscous zone **307** to the setting zone **309** downstream from the viscous zone **307**. In the setting zone **309**, the glass ribbon **103** is set from a viscous state to an elastic state. The method further includes the step of drawing the glass ribbon **103** into the elastic zone **311** downstream from the setting zone **309**. Optionally, the cutting device **303** may then be used to cut distinct glass sheets **305** from the glass ribbon **103** for further processing. Although not shown, the edges of the glass ribbon may be trimmed and/or the glass ribbon may be coiled into a storage spool for carrying out further cutting techniques at another location.

[0061] The method further includes the step of controlling a transverse temperature profile of the glass ribbon **103** along the width of the glass ribbon **103** in at least one of the viscous zone **307**, the setting zone **309** and the elastic zone **311**. The step of controlling the temperature profile includes selectively removing heat from at least one of a plurality of cooling coils **403a-e** positioned along the cooling axis **405a** that is transverse to the draw direction **207**.

[0062] As shown in **FIG. 6**, the step of removing heat from the cooling coils can be carried out by circulating fluid, such as water, through the at least one tube **501** that forms the corresponding cooling coil. Circulating fluid through a tube can avoid damaging or otherwise contaminating electrical components associated with the heating device or other parts of the fusion draw apparatus **101** with fluid such as water.

[0063] As further shown in **FIG. 6**, the method can selectively operate the cooling coils **403a-e** to control the transverse temperature profile of the glass ribbon **103**. For example, the heat sensors **627** can sense the temperature of the glass ribbon **103** at different positions along the width of the glass ribbon. The heat sensors **627** can then send feedback to the computer controller **619** by way of communication lines **629**. Based on the feedback, the computer controller can adjust the pump **613** and or one or more of the solenoid flow valves **617** to independently adjust the cooling flow of fluid through one or more of the cooling coils **403a-e**. As such, methods are possible to adjust the cooling rate of at least one of the cooling coils **403a-e** without adjusting the cooling rate of at least another one of the cooling coils. Moreover, the plurality of cooling coils **403a-e** may be selectively operated based on temperature feedback to provide a control system that operates the cooling coils based on the sensed temperatures.

[0064] In further examples, the temperature profile can be controlled by selectively adding heat with at least one of the plurality of heat devices **413a-e** positioned along the cooling axis **405a**. In one example, the computer controller **619** can automatically adjust the heat added by each of the heating devices based on feedback sensed by the heat sensors **627**. Example methods can involve cooling with the heating devices **413a-e** without the use of the cooling coils **403a-e**. For example, the fluid may be drained out of the cooling coils, wherein the high-temperature metal of the at least one tube of the cooling devices allows the cooling coils to maintain structural integrity within the high temperature environment while providing little, if any, interference of heating the portions of the glass ribbon with the respective heating devices. In operation, the outer portions of the glass ribbon **103** near the edges **103a**, **103b** naturally tend to cool faster than the central portion of the glass ribbon **103**. As such, the temperature sensed by the outer sensors **627** associated with cooling zones **601a**, **601e** may determine that the outer portions of the glass ribbon **103** are cooling too quickly. In response, the computer controller **619** may activate the outer pair of heating devices **413a**, **413e** at a higher temperature relative to the remaining heating devices to provide a more even cooling of the glass ribbon across the width.

[0065] Alternatively, the heating devices may be turned off, wherein cooling is conducted with the cooling coils **403a-e**. In this example, temperature sensed by the heat sensor **627** associated with the central cooling zone **601c** may indicate that the central portion of the glass ribbon includes a relatively high temperature. In response, the computer controller **619** may increase the flow rate of fluid through the inner cooling coil **403c** to increase the cooling rate of the central cooling zone **601c**. As such, the central cooling coil may cool at a relatively higher rate to provide a more even cooling of the glass ribbon across the width.

[0066] In still further examples, the heating devices and cooling coils may be operated at the same time. For instance, heating applied by the heating device can be modified by cooling with a respective cooling coil to provide fine tuning of the effective cooling rate applied by the respective cooling zone.

[0067] As further illustrated, the relatively different transverse widths "$\mathbf{W_1}$", "$\mathbf{W_2}$" and "$\mathbf{W_3}$" may be provided to help facilitate larger heat transfer in areas where cooling rate adjustment is needed the most. For example, the outer heating devices **413a**, **413e** may be associated with relatively larger widths "$\mathbf{W_1}$" to help apply heat at a greater rate to the outer edges to compensate for faster cooling at the edges that would otherwise provide an undesirable transverse temperature profile.

[0068] It will be apparent to those skilled in the art that various modifications and variations can be made to the present disclosure without departing from the spirit and scope of the invention. Thus, it is intended that the present invention cover the modifications and variations of this disclosure provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

1. An apparatus for producing glass ribbon comprising:

a drawing device configured to draw molten glass into a glass ribbon in a draw direction along a draw plane of the apparatus; and

a cooling apparatus including a plurality of cooling coils positioned along a cooling axis of the apparatus extending transverse to the draw direction and configured to control a transverse temperature profile of the glass ribbon along the cooling axis, wherein each cooling coil is fabricated from at least one tube and configured to circulate fluid through the at least one tube to remove heat from the cooling coil.

2. The apparatus of claim 1, wherein the plurality of cooling coils are aligned relative to one another in a row of cooling coils.

3. The apparatus of claim 1, wherein the at least one tube comprises a single substantially continuous tube that is bent into a compact shape.

4. The apparatus of claim 3, wherein the compact shape comprises a serpentine shape.

5. The apparatus of claim 3, wherein the compact shape extends along a cooling plane.

6. The apparatus of claim 5, wherein the cooling plane faces the draw plane.

7. The apparatus of claim 6, wherein the cooling plane is substantially parallel to the draw plane.

8. The apparatus of claim 1, wherein each cooling coil of the plurality of cooling coils is independently operable from another cooling coil of the plurality of cooling coils.

9. The apparatus of claim 1, wherein the plurality of cooling coils each include a corresponding transverse width extending along the cooling axis of the apparatus, wherein the transverse width of at least one of the plurality of cooling coils is greater than the transverse width of another of the plurality of cooling coils.

10. The apparatus of claim 1, wherein the plurality of cooling coils each include a corresponding transverse width extending along the cooling axis of the apparatus, wherein each transverse width of the plurality of cooling coils is substantially less than a draw width of the apparatus.

11. The apparatus of claim 10, wherein the plurality of cooling coils are aligned relative to one another in a row of cooling coils having a length that is greater than or about equal to the draw width of the apparatus.

12. The apparatus of claim 1, further including a plurality of heat sensors configured to monitor the temperature of the glass ribbon at different positions along the transverse profile.

13. The apparatus of claim 1, further comprising a control system configured to selectively operate the plurality of cooling coils based on corresponding temperatures sensed at different positions along the transverse profile.

14. The apparatus of claim 1, further comprising a plurality of heating devices positioned along the cooling axis of the apparatus.

15. The apparatus of claim 14, further comprising a plurality of temperature control modules positioned along the cooling axis of the apparatus, wherein each of the control modules corresponds to least one of the plurality of cooling coils and at least one of the plurality of heating devices.

16. The apparatus of claim 15, wherein each temperature control module is mounted with respect to the draw device such that the corresponding cooling coil is positioned between the corresponding heating device and the draw plane of the apparatus.

17. The apparatus of claim 16, wherein each temperature control module is removably mounted with respect to the draw device.

18. The apparatus of claim 15, wherein the corresponding cooling coil and the corresponding heating device of at least one temperature control module include substantially the same width.

19. The apparatus of claim 15, further comprising a controller configured to operate each control module to simultaneously cool with the corresponding cooling coil and heat with the corresponding heating device.

20. A method of producing a glass ribbon including the steps of:

(I) drawing molten glass in a draw direction into a viscous zone to form a glass ribbon including opposed edges extending in the draw direction, wherein the opposed edges are spaced apart along a width of the glass ribbon that is transverse to the draw direction;

(II) drawing the molten glass from the viscous zone into a setting zone downstream from the viscous zone, wherein the glass ribbon is set from a viscous state to an elastic state;

(III) drawing the glass ribbon into an elastic zone downstream from the setting zone; and

(IV) controlling a transverse temperature profile of the glass ribbon along the width of the glass ribbon in at least one of the viscous zone, the setting zone and the elastic zone, wherein the step of controlling the temperature profile includes selectively removing heat from at least one of a plurality of cooling coils positioned along a cooling axis that is transverse to the draw direction.

21. The method of claim 20, further comprising the step of operating the cooling coils such that each cooling coil forms an associated one of a plurality of cooling zones that are aligned with one another to create a row of cooling zones along the cooling axis.

22. The method of claim 20, wherein removing heat from the at least one of the plurality of cooling coils is carried out by circulating fluid through at least one tube that forms the corresponding cooling coil.

23. The method of claim 20, further comprising the step of adjusting a cooling rate of at least one of the cooling coils without adjusting a cooling rate of at least another one of the cooling coils.

24. The method of claim 20, further comprising the step of selectively operating the plurality of cooling coils to control the transverse temperature profile of the glass ribbon.

25. The method of claim 20, further comprising the steps of sensing a temperature of the glass ribbon at different positions along the width of the glass ribbon and selectively operating the plurality of cooling coils based on the sensed temperatures.

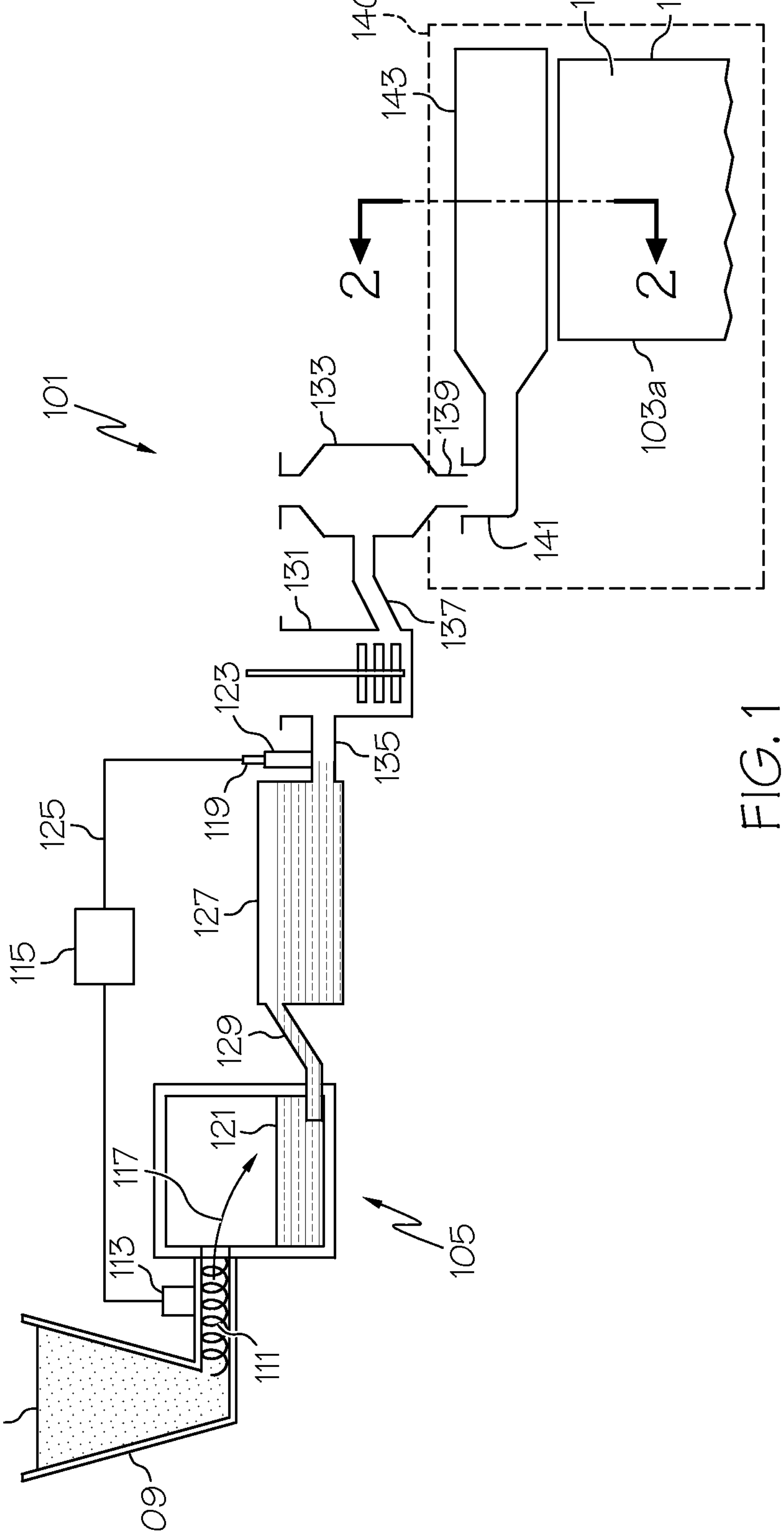
26. The method of claim 20, wherein the step of controlling the temperature profile includes selectively adding heat with at least one of a plurality of heating devices positioned along the cooling axis.

27. The method of claim 26, further comprising the step of providing a plurality of temperature control modules positioned along the cooling axis, wherein each of the control modules includes at least one of the plurality of cooling coils and at least one of the plurality of heating devices.

28. The method of claim 27, further comprising the step of replacing one of the control modules with a new control module.

29. The method of claim 28, wherein the step of replacing is carried out while drawing molten glass in the draw direction.

30. The method of claim 27, further comprising the step of operating at least one of the control modules to simultaneously cool with the corresponding cooling coil and heat with the corresponding heating device.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103b
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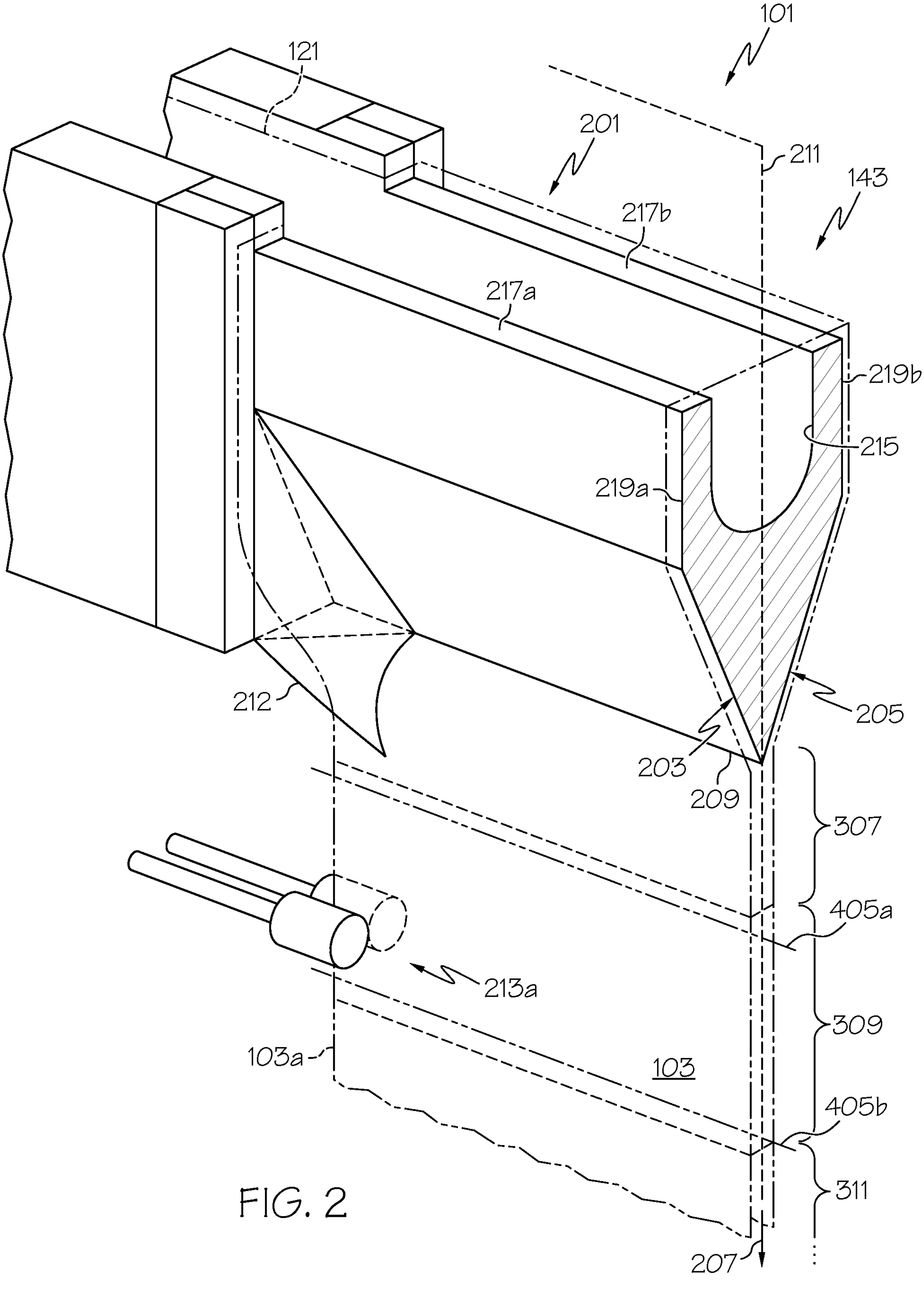
2

FIG. 1



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405a
213a
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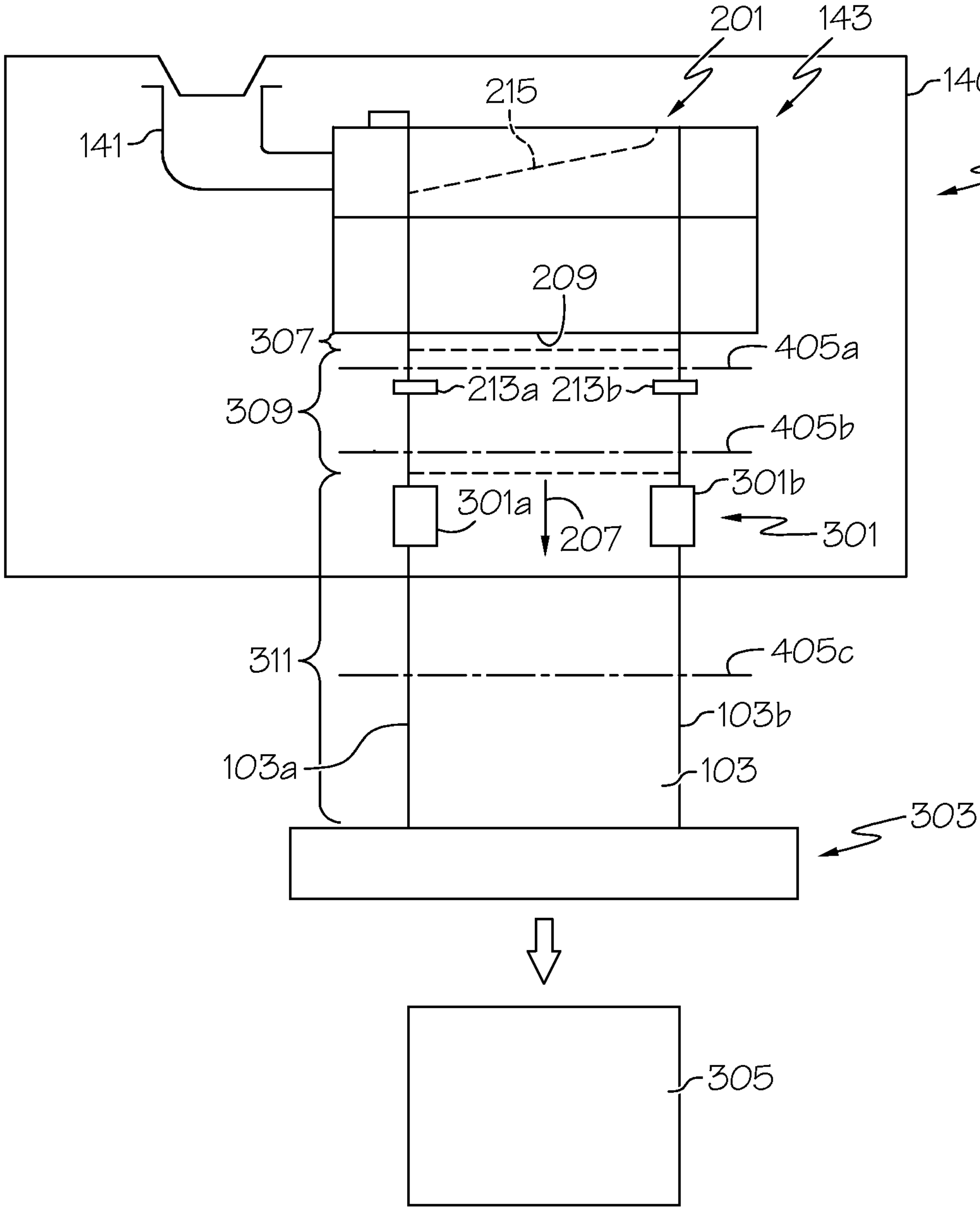
405b
311
207

FIG. 2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307
405a
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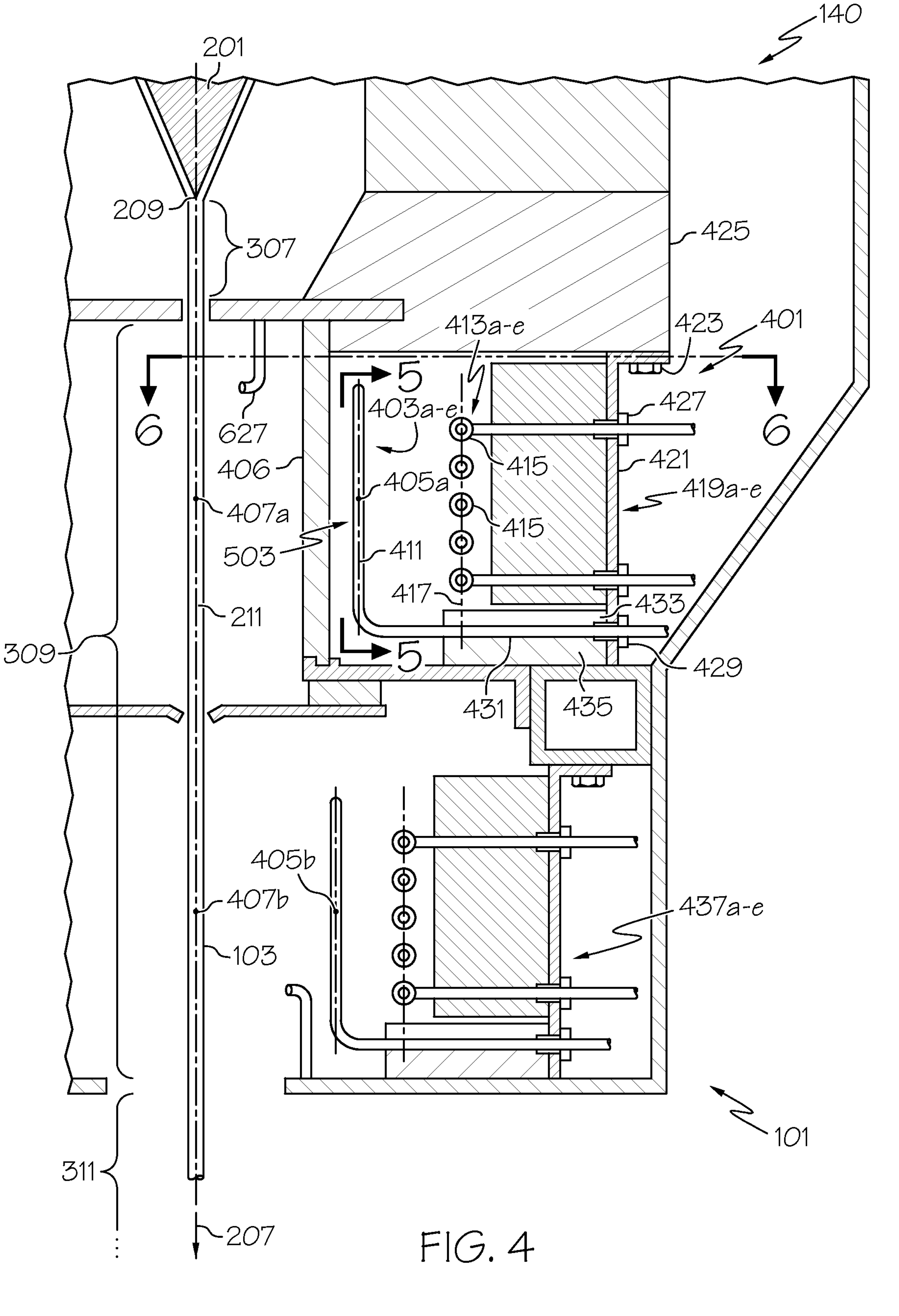
207
311
405c
103b
103a
103
303
305

FIG. 3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423
401
6
6
627
403a-e
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406
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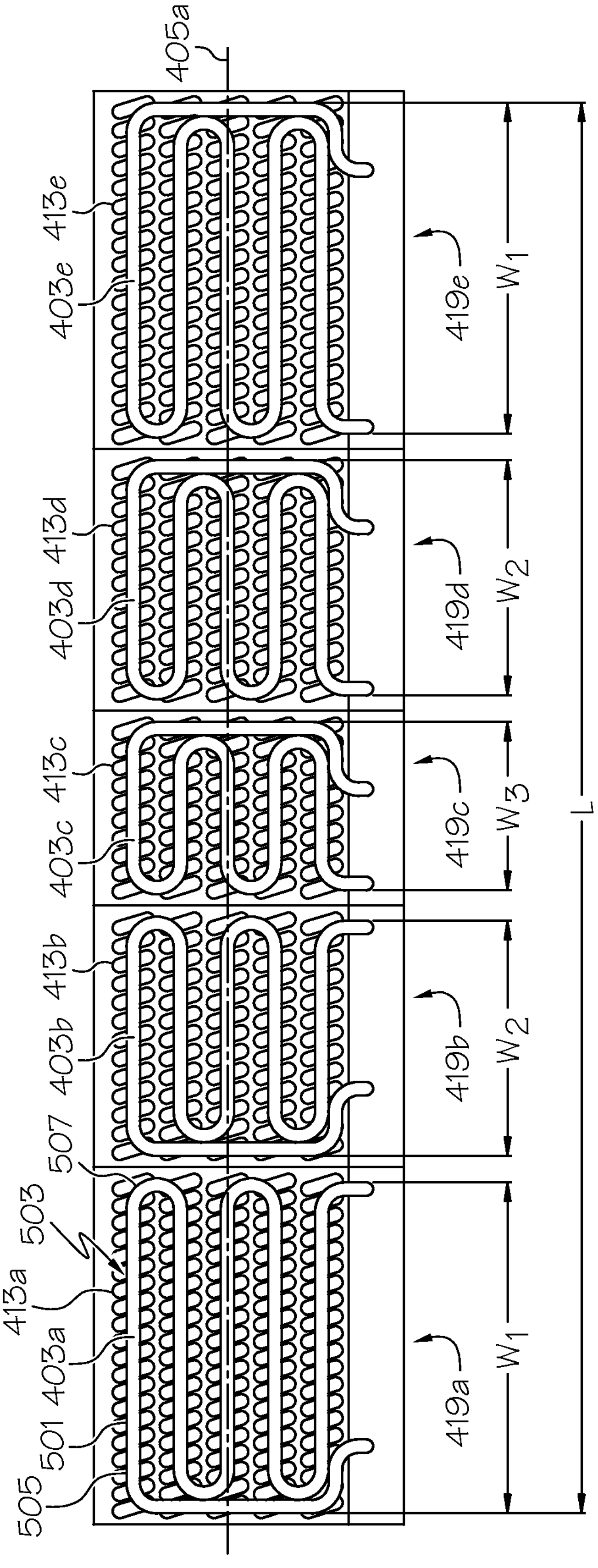
405a
419a-e
407a
415
503
411
417
433
211
5
5
309
429
431
435
405b
437a-e
407b
103
101
311
207

FIG. 4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413e
403e
419e
W1
413d
403d
419d
W2
413c
403c
419c
W3
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413b
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419b
W2
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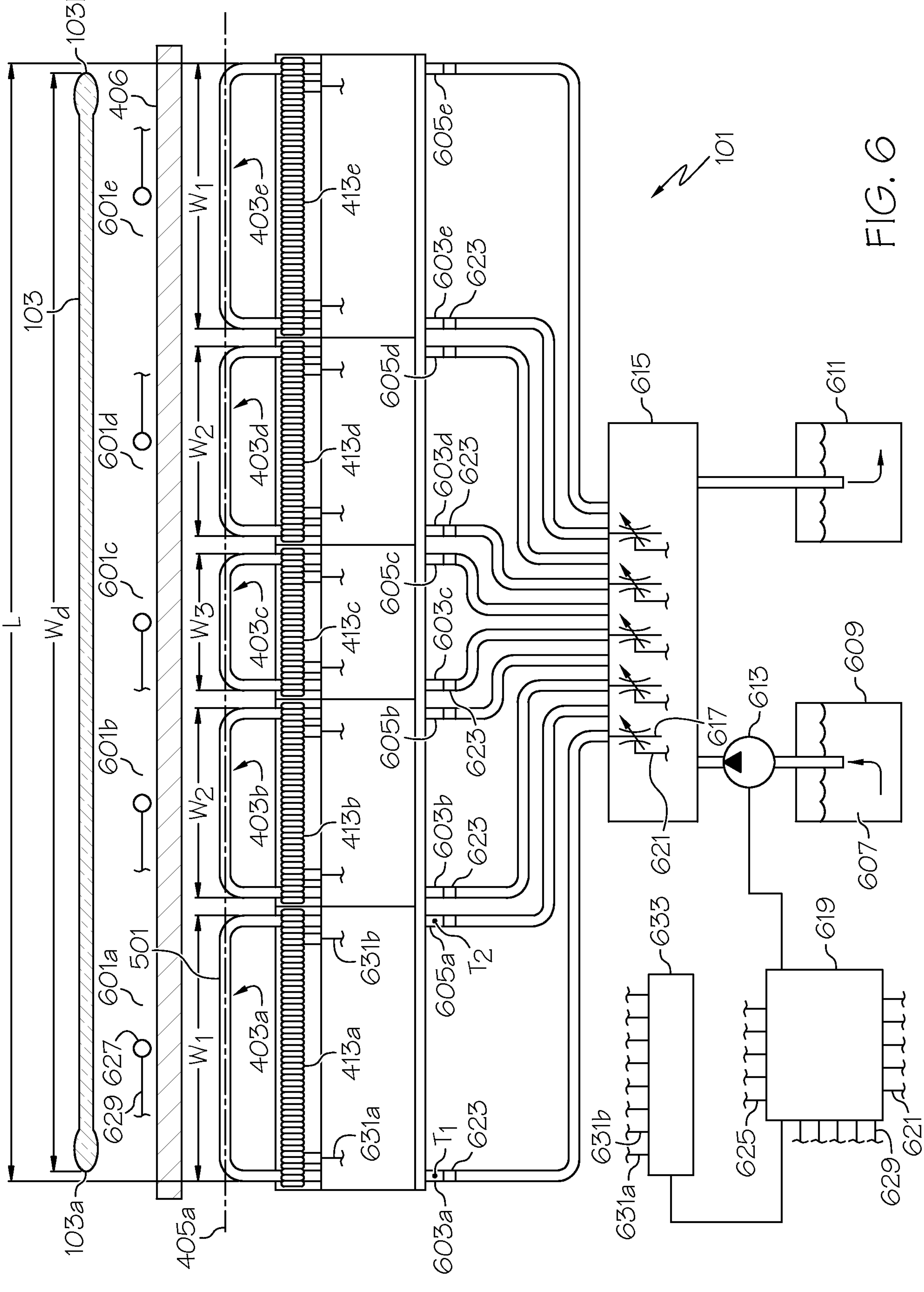
503
413a
403a
501
505
419a
W1

FIG. 5


103b
103
103a
L
Wd
406
405a
501
601a
601b
601c
601d
601e
627
629
W1
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W3
403a
403b
403c
403d
403e
413a
413b
413c
413d
413e
631a
631b
603a
603b
603c
603d
603e
605a
605b
605c
605d
605e
623
T1
T2
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615
611
613
617
621
609
607
619
625
633

FIG. 6

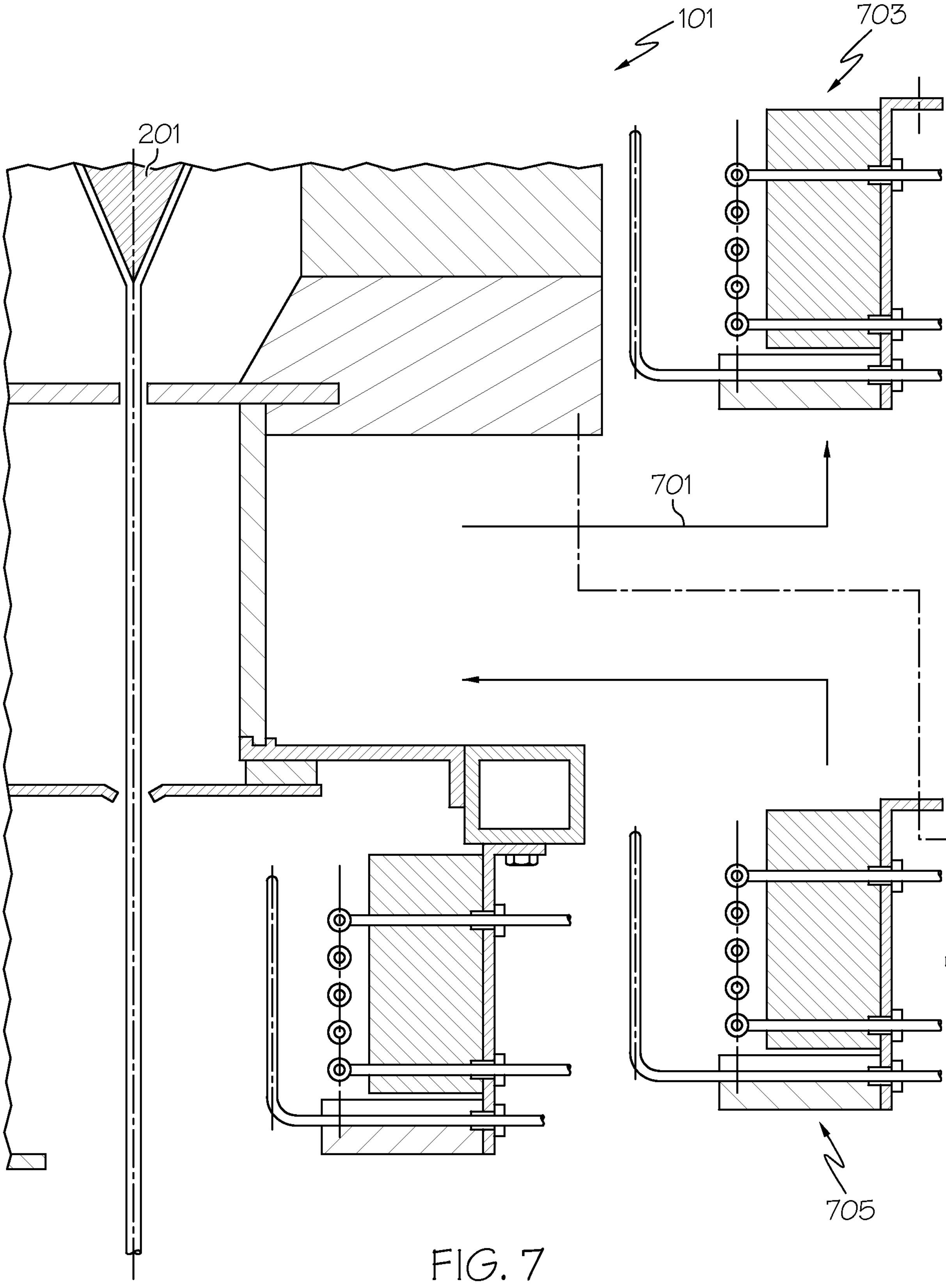

FIG. 7