



- (51) **International Patent Classification:**
C03B 35/00 (2006.01)
- (21) **International Application Number:**
PCT/US20 12/066965
- (22) **International Filing Date:**
29 November 2012 (29.11.2012)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
61/565,021 30 November 2011 (30.11.2011) US
- (71) **Applicant:** CORNING INCORPORATED [US/US]; 1 Riverfront Plaza, Corning, New York 14831 (US).
- (72) **Inventors; and**
- (71) **Applicants :** AMSDEN, Jeffrey Michael [US/US]; 3 Davis Avenue, Hammondsport, New York 14840 (US). ANDERSON, Michael J. [US/US]; 121 Lincoln Rd., Horseheads, New York 14845 (US). DYER, Gail [US/US]; 94 Evergreen Ave., Elmira, New York 14905 (US). KABEL, Scott Michael [US/US]; 568 Steege Hill Road, Corning, New York 14830 (US). LIU, Stephen Kuo-Rui [US/US]; 2152 Davis Road, Corning, New York 14830 (US). WASSON, Kevin Lee [US/US]; 45 Thornapple Drive, Elmira, New York 14903 (US).
- (74) **Agent:** SCHAEFERLE, Timothy M; Corning Incorporated, Intellectual Property Department, SP-Ti-03-01, Corning, New York 14831 (US).

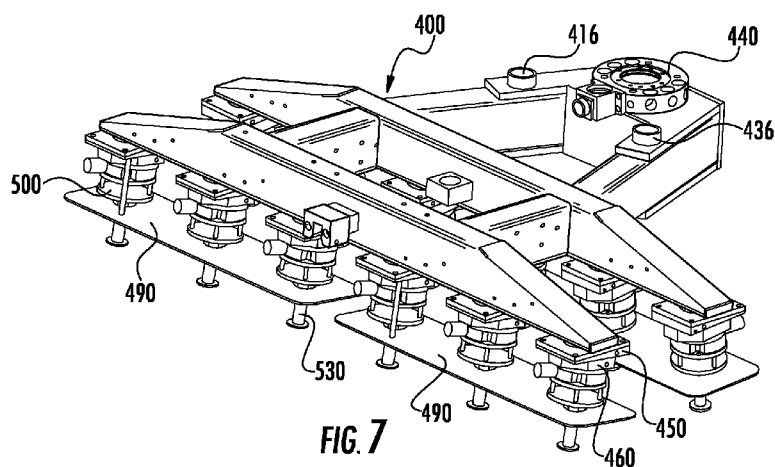
(81) **Designated States** (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report (Rule 48.2(g))

(54) **Title:** DEVICE AND METHODS FOR PICKING AND PLACING HOT 3D GLASS



(57) **Abstract:** A system for picking and placing glass articles from a first location to a second location, the second location including a thermal reforming apparatus for transforming the glass articles from 2D glass articles to 3D glass articles includes a robot having an end effector, the end effector including a compliance assembly having at least six degrees of freedom. The compliance assembly is in fluid communication with both an open pneumatic system and a closed pneumatic system, the open pneumatic system providing a partial vacuum to a portion of the compliance assembly for grabbing the glass article, and the closed pneumatic system for activating a centering function for a portion of the compliance assembly.

DEVICE AND METHODS FOR PICKING AND PLACING HOT 3D GLASS

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Serial No. 61/565021 filed on November 30, 2011 the content of which is relied upon and incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION*Field of the Invention*

[0002] The present disclosure relates generally to manufacture of three-dimensional (3D) glass articles by thermal reforming of two-dimensional (2D) glass sheets.

Technical Background

[0003] There is a large demand for 3D glass covers for portable electronic devices such as laptops, tablets, and smart phones. A particularly desirable 3D glass cover has a combination of a 2D surface, for interaction with a display of a portable electronic device, and a 3D surface, for wrapping around the edge of the display. The 3D surface may be an undevelopable surface, i.e., a surface that cannot be unfolded or unrolled onto a plane without distortion, and may include any combination of bends, corners, and curves. The bends may be tight and steep. The curves may be irregular. Such 3D glass covers are complex and difficult to make with precision using machining processes such as grinding and milling. On the other hand, thermal reforming has been used to form 3D glass articles from 2D glass sheets in other types of applications. The present disclosure relates to a system, apparatus and method of picking and placing the glass articles, before thermal reforming and after thermal reforming in such manner so as not to damage the glass articles that enables use of thermal reforming to make 3D glass covers such as described above.

SUMMARY

[0004] A system for handling a glass article that is being transported to and from a thermal reforming apparatus may include at least one robot in communication with at least one compliance assembly. The compliance assembly may include at least one first portion and at least one second portion, the at least one first portion including a compliance device for accommodating a positional error between a target location and an actual location. At least a portion of the compliance device may be capable of at least three degrees of freedom. The at least one second portion may include a compliance device adapter for interfacing between the

compliance device and at least one glass article, at least a portion of the compliance device adapter capable of at least three other degrees of freedom.

[0005] The system may further include at least one open pneumatic system in fluid communication with the compliance device adapter and at least one closed pneumatic system in fluid communication with the at least one first portion of the compliance assembly.

[0006] In exemplary embodiments, the system may include a manifold having at least one connecting means for connecting the manifold to the robot, at least one adapter plate for receiving the at least one compliance assembly. The manifold may also define and at least one chamber, for example, at least one vacuum chamber for buffering a vacuum from the open pneumatic system. The open pneumatic system may be in fluid communication with the at least one chamber, the open pneumatic system adapted to apply a fluid pressure that is lower than an ambient pressure through the at least one chamber, creating a partial vacuum in the at least one chamber.

[0007] In exemplary embodiments, the at least one closed pneumatic system may be adapted to apply another fluid pressure, the other fluid pressure including a positive fluid pressure greater than the ambient pressure and a negative fluid pressure less than the ambient pressure.

[0008] The system may also include at least one input nest assembly and an output nest assembly, both assemblies including at least one cross bar receiving frame, at least one cross bar for inserting into the at least one cross bar receiving frame and at least one compound angle nest frame for receiving the at least one cross bar receiving frame. In exemplary embodiments at least a portion of the input nest assembly may be made from a polymer and at least a portion of the output nest assembly may be made from a heat resistant material.

[0009] The system may further include at least one wedge adapter plate to enable picking and placing from an array of molds, and at least one compound angle adapter plate having a compound angle that corresponds to the compound angle nest frame.

[0010] It is to be understood that both the foregoing general description and the following detailed description are exemplary of the present disclosure and are intended to provide a framework for understanding the nature and character of the present disclosure as it is claimed. The accompanying drawings are included to provide a further understanding of the present disclosure and are incorporated in and constitute a part of this specification. The drawings illustrate various embodiments of the disclosure and together with the description serve to explain the principles and operation of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The following is a description of the figures in the accompanying drawings. The figures are not necessarily to scale, and certain features and certain views of the figures may be shown exaggerated in scale or in schematic in the interest of clarity and conciseness.

[0012] **FIG. 1** is a perspective view of a continuous glass molding system;

[0013] **FIG. 2** is a cross-section of a heating module;

[0014] **FIG. 3** is a perspective view of a system for picking and placing articles;

[0015] **FIG. 4** is a bottom perspective view of a robot assembly from the system of **FIG. 3**;

[0016] **FIG. 5** is a perspective partial cut-away view of a manifold;

[0017] **FIG. 6** is a perspective view of the bottom of the manifold of **FIG. 5**;

[0018] **FIG. 7** is a top perspective view of a robot end effector for picking and placing;

[0019] **FIG. 8** is a side view of a portion of the robot end effector of **FIG. 7**;

[0020] **FIG. 9** is a partially exploded view of a compliance assembly;

[0021] **FIG. 10** is a perspective view of a suction cup;

[0022] **FIG. 11** is a perspective view of the compliance assembly of **FIG. 9** having the suction cup of **FIG. 10**;

[0023] **FIG. 12** is a perspective view of a wedge adapter plate;

[0024] **FIG. 13** is a perspective view of a compound angle adapter plate;

[0025] **FIG. 14** is a close-up perspective view of a portion of the end effector of **FIG. 7** showing the adapter plates of **FIGS. 12** and **13**;

[0026] **FIG. 15** is a representation of degrees of freedom of the compliance assembly of **FIG. 11**;

[0027] **FIG. 16** is a perspective view of the compliance assembly of **FIG. 11** loading an article onto a mold;

[0028] **FIGS. 17** and **18** are side views of the end effector in positions for placing and picking an article on a mold;

[0029] **FIG. 19** is perspective view of a representative input/output nest assembly;

[0030] **FIG. 20** is a perspective view of a compound angle nest frame for the input/output nest assembly of **FIG. 19**;

[0031] **FIGS. 21** and **22** are perspective views of an embodiment of an input/output cross bar receiving frame and input/output crossbars for the input/output nest assembly of **FIG. 19**;

[0032] FIGS. 23 and 24 are partial close up views of the system of FIG. 3 showing a docking area for the end effector of FIG. 7;

[0033] FIG. 25 is a representation of a series of locations for the article being placed on the mold; and

[0034] FIGS. 26A, 27A and 28A are representative drawings of articles being heated without benefit of a controlled thermal gradient;

[0035] FIGS. 26B, 27B and 28B are corresponding representative drawings of articles being heated with benefit of a controlled thermal gradient; and

[0036] FIGS. 26C, 27C and 28C are relative heat scales corresponding to FIGS. 26A, 27A and 28A and FIGS. 26B, 27B and 28B showing increasing temperatures in the direction of the arrows.

DETAILED DESCRIPTION

[0037] A continuous glass molding system **100** (FIG. 1) is disclosed for producing 3D glass articles from 2D glass sheets by thermal refoming. Continuous glass molding system **100** includes a primary rotary table system **102** having a primary rotary indexing table **104**. Primary rotary table system **102** can be any custom or commercial rotary table system capable of translating primary rotary indexing table **104** along a circular or looped path through a selected rotational angle. (Here and below, a non-rotary table system, such as a linear table system, with a non-rotary indexing table, such as a linear indexing table, may be used in lieu of a rotary table system with a rotary indexing table.) Several stations **106** are defined on primary rotary indexing table **104**, and each station **106** includes a support for a mold **108**. Heating modules **110** are arranged along primary rotary indexing table **104**, and primary rotary indexing table **104** can be rotated to allow each station **106** to be selectively indexed with any one of heating modules **110**. In an exemplary embodiment, station **106** being indexed with heating module **110** may have mold **108** supported at station **106** being disposed within heating module **110**, allowing a 2D glass sheet supported on mold **108** to be formed into a 3D glass article in the heating module **110**. Typically, the number of stations **106** will exceed the number of heating modules **110** so that only some of stations **106** may be indexed with heating modules **110** at any time. In an exemplary embodiment, there may be twenty-four stations **106** and eighteen heating modules **110** (FIG. 1), but any number of stations **106** and heating modules **110** maybe contemplated in the system. Each station **106** not being indexed with heating module **110** maybe open to the air to allow operator access for performing such

operations as loading of a 2D glass into a mold, unloading of a 3D glass article from a mold, cleaning of a mold, and repairing or replacement of a mold.

[0038] Continuous glass molding system **100** may include an indexing period followed by a wait period, defining a cycle. During the indexing period, for example, primary rotary indexing table **104** may be rotated by some rotational angle α in some direction β (which may be clockwise or counterclockwise), which results in a particular configuration of stations **106** being indexed with heating modules **110**. The rotational speed may be constant or varied during the indexing period. By way of example, such a variation may include an initial acceleration, followed by a steady speed, followed by a final deceleration. For a first cycle, it may be that only one of stations **106** being indexed with heating modules **110** would support a mold **108** carrying a 2D glass sheet. After a few more cycles, for example, all of stations **106** being indexed with heating modules **110** would each support mold **108** carrying a 2D glass sheet or mold **108** carrying a 3D glass article. Whether mold **108** is carrying a 2D glass sheet or a 3D glass article would depend on the position of mold **108** along the sequence of heating modules **110**. During the wait period, thermal reforming of the 2D glass sheet into the 3D glass article may be carried out at each station **106** that is indexed with heating module **110**. For continuous production, for example, it may not be feasible to complete thermal reforming in a single heating module **110**, in which case thermal reforming may be distributed among a series of heating modules **110**. A typical thermal reforming process may involve heating the 2D glass sheet to a forming temperature, e.g., a temperature in a temperature range corresponding to a glass viscosity of 10^7 Poise to 10^{11} Poise, and then allowing the heated 2D glass sheet to sag against a mold surface to form the 3D glass article. Sagging is typically assisted by vacuum, i.e., by applying vacuum to the glass to draw the glass against the mold surface. After forming the 3D glass article, the 3D glass article is cooled to a temperature below the strain point of the glass, which would allow handling of the 3D glass article. For distributed thermal reforming, a segment of heating modules **110** could be devoted to heating the 2D glass sheet to a forming temperature, another segment of the heating modules **110** could be devoted to forming the 2D glass sheet into the 3D glass article, and another segment of the heating modules **110** could be devoted to cooling the 3D glass article.

[0039] The cycle described above is repeated as many times as desired for continuous production of 3D glass articles from 2D glass sheets by thermal reforming. While the cycles are ongoing, additional activities may be taking place, for example, unloading 3D glass articles

from molds and loading new 2D glass sheets into empty molds. As primary rotary indexing table **104** is rotated, each of stations **106** supporting mold **108** carrying a 3D glass article will eventually become exposed to the air, allowing access to the 3D glass article. In exemplary embodiments, a robot **112** may then be used to unload the 3D glass article from the mold **108** onto an unloading area **114**. Also, another robot **116** maybe used to load new 2D glass sheets from a loading area **118** onto the emptied mold **108**. In some embodiments, a single robot **310** (see **FIG. 3**) maybe used to both unload 3D glass articles and load 2D glass sheets. To enable a high throughput, the 2D glass sheets are preheated before being loaded onto the mold **108**. For this purpose, loading area **118** may include a secondary rotary indexing system **120**, which includes a secondary rotary table **122**. Several stations may be defined on secondary rotary indexing table **122**, as in the case of the primary rotary indexing table **104**. In one embodiment, secondary rotary indexing table **122** may be disposed in a furnace **124**. For example, 2D glass sheets are first loaded onto the stations of secondary rotary indexing table **122** and preheated in the furnace **124**. In one embodiment, preheating includes flowing heated gas, such as nitrogen, over the 2D glass sheets. The 2D glass sheets maybe heated to a preheat temperature below the forming temperature. Robot **116** may then transfer the preheated 2D glass sheets onto stations **106** of the primary rotary indexing table **104** for further heating and forming into 3D glass articles by thermal reforming. In one example, secondary rotary indexing table **122** may have six stations, but there is no particular restriction on how many stations may be defined on secondary rotary indexing table **122**. Robots **116**, **112** may use vacuum or suction cups to grab the 2D glass sheets and 3D glass articles, respectively. In exemplary embodiments, the vacuum or suction cups or other means of grabbing the 2D glass sheets and 3D glass articles should not scratch the glass, mar the glass, or leave residue on the glass.

[0040] A heating module **200** (**FIG. 2**) that could be used as any one of heating modules **110** described above may include a housing **202**, which defines a heating enclosure **204**. The wall of housing **202** may have a wall layer **203**, for example, made of a refractory material and surrounding heating enclosure **204**, a wall layer **205**, for example, made of a refractory material and surrounding portions of wall layer **203**, and a wall layer **207**, for example, made of insulating material and surrounding wall layers **203**, **205**. The insulated refractory wall of housing **202** allows the temperature in heating enclosure **204** to be controllable. An upper portion **209** of heating enclosure **204** serves as a temperature-controlled space in which a 2D

glass sheet is heated while on a mold and then formed into a **3D** glass article. For this purpose, an array of radiant heaters 206 may be disposed in upper portion 209 of heating enclosure 204. A radiation emitter body 208 may also be disposed in upper portion 209 of heating enclosure 204, below the array of radiant heaters 206. In one embodiment, the radiation emitter body 208 may be secured to housing 202, for example, by inserting the ends of radiation emitter body 208 into grooves 211 in refractory layer 203 of housing 202.

[0041] A radiation reflector surface 210 may be disposed in heating enclosure 204, below the radiation emitter body 208. In exemplary embodiments, radiation reflector surface 210 may be an integral part of the heating module 200, e.g., radiation reflector surface 210 may be supported on a surface in heating enclosure 204 or secured to the wall of housing 202. In such embodiments, radiation reflector surface 210 would be stationary. In other embodiments, radiation reflector surface 210 may be provided by or formed on a surface of an indexing table 217, for example, corresponding to primary rotary indexing table 104 (see **FIG. 1**). In such embodiments, radiation reflector surface 210 may be capable of moving through heating enclosure 204 with indexing table 104. Radiation reflector surface 210 may have a receiving area, which is a designated area for receiving an object to be heated. In one embodiment, radiation reflector surface 210 may include a receiving hole 212 for receiving the object to be heated. For glass molding applications, receiving hole 212 may be sized to receive a mold on which glass is or may be supported. A lower portion 213 of heating enclosure 204 may include an opening 215 for passage of indexing table 217 through heating enclosure 204. By way of example, a station on the indexing table 217 (**FIG. 2**) has been indexed with heating module 200 so that a mold 214 at the station is placed in heating enclosure 204. Mold 214 may also be placed in receiving hole 212 of radiation reflector surface 210, for example, which may be arranged in heating enclosure 204. The placement of mold 214 in receiving hole 212 may allow radiation reflector surface 210 to surround a periphery of mold 214. With this placement, the top of mold 214 may or may not be flush with radiation reflector surface 210. The array of radiant heaters 206 emits radiation, which may be received at a top surface 222 of radiation emitter body 208 and absorbed into radiation emitter body 208. Radiation emitter body 208 in turn emits the absorbed radiation from a radiation emitter body bottom surface 216, for example, towards radiation reflector surface 210 so that the radiation may be used to heat mold 214 (as well as the glass on the mold). In some embodiments, the array of radiant heaters 206 in combination with radiation emitter body 208 may provide a thermally uniform

heat source for mold 214 (and the glass on the mold). The radiation not used in heating, for example, not absorbed by, mold 214 (and the glass on the mold) maybe reflected back to radiation emitter body 208 by radiation reflector surface 210.

[0042] In some embodiments, radiation reflector surface 210 may be a flat surface. In one embodiment, radiation emitter body bottom surface 216 is flat and opposed to radiation reflector surface 210. In one embodiment, radiation reflector surface 210 and radiation emitter body bottom surface 216 may be substantially parallel to each other. Radiation reflector surface 210, in exemplary embodiments, may be a surface of a plate or may be plating on any suitable surface, such as a surface of an indexing table. In some embodiments, radiation reflector surface 210 maybe made of a refractory material, e.g., a silicon carbide or other such suitable ceramic material as ZIRCAR, both commercially available. In some embodiments, radiation reflector surface 210 may have a relatively low emissivity, for example, an emissivity less than 0.4. In some embodiments, radiation emitter body 208 maybe a plate. In some embodiments, radiation emitter body 208 may have a relatively high emissivity, for example, an emissivity greater than 0.8. In exemplary embodiments, suitable materials for radiation emitter body 208 and radiation reflector surface 210 should be appropriate for the high temperatures that would be encountered within heating enclosure 204. For an infinite parallel plate heat system, along with selecting the emissivity of the radiation reflector surface 210 to be low, for example, less than 0.4, the area of the radiation emitter body bottom surface 216 may be selected to be much larger than the area of receiving hole 212 in radiation reflector surface 210 or the area of the top of mold 214. In some embodiments, the area of radiation emitter body bottom surface 216 may be approximately 9 times larger than the area of receiving hole 212 or the area of the top of mold 214. The span of radiation emitter body bottom surface 216 may be greater than or approximately the same as the span of radiation reflector surface 210. In exemplary embodiments, the radiation view factor of the system may be selected to maximize the efficiency of heat transfer of the system. This may be achieved in some embodiments by locating the top of mold 214 (or radiation reflector surface 210, which includes receiving hole 212 for the mold 214) close to radiation emitter body bottom surface 216, which in exemplary embodiments may be from 10 millimeters (mm) to 50 mm from bottom surface 216.

[0043] In some embodiments, the array of radiant heaters emits radiation in the infrared range. In exemplary embodiments, the array of radiant heaters 206 emits radiation in the

middle infrared range, i.e., $1.5\mu\text{m}$ to $5.6\mu\text{m}$. Alternatively, the array of radiant heaters **206** may emit radiation at a wider infrared range and a suitable filter between radiant heaters **206** and radiation emitter body **208** may be used to restrict the wavelength of radiation that may be absorbed by radiation emitter body **208** to the middle infrared range. The middle infrared range is useful for preferential heating of glass on mold, as described in U.S. Patent Application Publication No. 20100000259 (Ljerka Ukrainczyk; 7 January 2010). The preferential heating is such that the glass is hotter than the mold at and during the time the glass is formed into a 3D shape on the mold. Additional radiant heaters **218** may be arranged between the array of radiant heaters **206** and radiation emitter body **208** to provide additional heat to radiation emitter body **208** where needed. For example, additional heat may be needed in portions of radiation emitter body **208** near the periphery of heating enclosure **204**. The additional radiant heaters **218** and the array of radiant heaters **206** may be controlled to uniformly heat radiation emitter body **208** so that radiation emitter body **208** uniformly heats mold **214** (and glass on the mold). The temperature of radiation emitter body **208** or of the space between the heaters **206**, **218** and the radiation emitter body **208** may be monitored using suitable temperature sensors, and the output of the sensors maybe used to control the output of radiant heaters **206**, **218**. The ends of radiant heaters **206**, **218** protrude through the wall of housing **202** and maybe encased, for example, in perforated end plates **220** mounted on the exterior of housing **202**. These ends may include electrical connectors for connecting radiant heaters **206**, **218** to an electrical source. To protect these electrical connectors, the perforations in perforated end plates **220** may be used to circulate cooling air around the electrical connectors.

[0044] By way of example, a mold assembly **226** is shown at the opening **215** (**FIG. 2**). Mold assembly **226** maybe supported, for example, at a station that is part of the indexing table **217**, where the station has been placed in the opening **215**, for example, through rotation or other movement of indexing table **217** through the heating enclosure **204**. Mold assembly **226** may include mold **214** mentioned above and a support **228** for mold **214**. In exemplary embodiments, mold support **228** may incorporate a tilting stage for tilting mold **214** while mold **214** is received in receiving hole **212** (or receiving area) of radiation reflector surface **210** to assist alignment of the glass on mold **214**. A suitable positioning system attaches mold support **228** to indexing table **217** so that mold assembly **226** may travel with indexing table **217**. Mold assembly **226** may further include a conduit (or conduits), for example, for applying

vacuum to mold 214 and a conduit (or conduits) for applying gas around mold 214. The gas applied around mold 214 maybe for cooling the 3D glass article on mold 214 after the 3D glass article has been formed. The details of an exemplary mold 214 are described in U.S. Patent Application Publication No. 201 10126588 (Joseph D. Malach; 2 June 2011). In exemplary embodiments, mold 214 may have a mold surface having a 3D profile that corresponds to the 3D shape of the glass article to be formed using mold 214. Mold 214 may also have ports through which vacuum can be applied to the glass to draw the glass against the mold surface. The ports may open to the mold surface and be in communication with the conduit(s) for applying vacuum to the mold 214.

[0045] In some embodiments, the handling of the glass article being transported to and from the thermal reforming apparatus may include robots 112, 116 (FIG. 1). In some embodiments, a system 300 (FIG. 3) for handling the glass article being transported to and from a thermal reforming apparatus, for example, continuous glass molding system 100 or pivoting mold table 290, may include at least one robot assembly 310 adapted to transport the glass articles from a first location, for example, an input table 330, to a second location, for example, continuous glass molding system 100 or pivoting mold table 290. For clarity, the disclosure will discuss glass articles being transported from input table 330 to pivoting mold table 290, though the disclosed system 300 may be applied to continuous glass molding system 100. Further, the glass articles may be transported by robot assembly 310 from, for example, pivoting mold table 290 to a third location, for example, at least one output table 320.

[0046] An exemplary robot assembly 310 may include, for example, a manipulating industrial robot 312 having a robotic arm suitable for attaching a robot end effector assembly 400. End effector assembly 400 may be attached to robot 312, for example, by means of such a coupling collar 440 as, for example, commercially available from Schunk GmbH & Co. KG (FIG. 4). Any suitable robot and coupling means maybe used. End effector assembly 400 may include at least one compliance assembly 500. In some embodiments, for example, those applications for picking and placing a single glass article at a time, compliance assembly 500 maybe directly connected to, for example, robots 112, 116, and 312 and may serve as the end effector for the respective robots. In exemplary embodiments where an array of glass articles are to be picked and placed, for example, as a group, end effector assembly 400 would include, for example, a manifold 410 capable of holding an array of compliance assemblies 500.

[0047] In exemplary embodiments, manifold 410 (FIGS. 5 and 6) may provide a cantilevered frame for holding an array of compliance assemblies 500. Collar 440 may attach to manifold 410 by collar interface 420. Manifold 410, in exemplary embodiments, maybe made from a rigid material, for example, a stainless steel tubing material that has such desirable properties as heat resistance and low mass. Manifold 410 may be a vacuum buffer chamber having a rear chamber 412 and a front chamber 432. In exemplary embodiments, rear 412 and front 432 chambers maybe in fluid communication with, for example, an open pneumatic system. The open pneumatic system, e.g., a vacuum system, maybe adapted to apply a fluid pressure to manifold 410 that is lower than an ambient pressure (nominal atmospheric pressure) through rear 412 and front 432 chambers, for example, creating a partial vacuum in rear 412 and front 432 chambers. The partial vacuum may traverse from at least one input port (not shown), through at least one of chambers 412, 432, through one of a rear 414 and a front 434 transition chamber to one of a rear 416 and a front 436 output port. Each of output port 416, 436 maybe attached to, for example, a vacuum hose or other such means of transferring a partial vacuum as part of the open pneumatic system. Manifold 410 may provide a buffered, steady supply of low fluid pressure that may not be subject to, for example, fluctuations in the performance of the open pneumatic system. Put another way, the supply of low fluid pressure at the input port may be definitively on or off, rather than being partially on or partially off.

[0048] Rear chamber 412 may be in fluid communication with rear transition chamber 414 by way of a rear transition port 427 for allowing the fluid pressure to pass freely from rear chamber 412 to rear transition chamber 414. Front chamber 432 may be in fluid communication with front transition chamber 434 by way of front transition port 437. In exemplary embodiments, chambers 412, 432 are offset from each other, requiring a structure 429, 439 to support and join the two chambers 412, 432. In an exemplary embodiment, structure 439 may also define a conduit that is in fluid communication with front chamber 432 and transition chamber 434. Structures 429 maybe a segregated chamber not in fluid communication with any other part of manifold 410.

[0049] End effector assembly 400 may receive compliance adapter assemblies 500 directly onto adapter plates 440. In some exemplary embodiments, manifold adapter plates 440 may receive at least one wedge adapter plate 450 (see FIG. 12 and 14) having two generally opposing surfaces, for example, at an angle 455 to each other in a single axis. Wedge adapter

plate **450** may be aligned so that the axis of angle **455** is oriented from front to rear relative to manifold **410**, but other arrangements may be contemplated. In some exemplary embodiments, wedge adapter plates **450** located on the front and the rear of manifold **410** may be aligned so that angles **455** open toward an area between the front and rear of manifold **410**, toward each other, causing the angled faces to point away from each other.

[0050] In some exemplary embodiments, compound angle adapter plate **460** (see **FIG. 13** and **14**) may be joined to wedge adapter plate **450**. In exemplary embodiments, compliance adapter assemblies **500** may be associated with at least one compound adapter plate **460**. Compound adapter plate **460** may include generally opposing surfaces that have two different angles between them, each angle in a different axis, for example, to correspond to angles that may be found on various article placement locations, as will be discussed. By way of example, one surface may be a reference surface and another surface generally opposed to the one surface may be a compound surface being at angles to the reference surface in at least two axes. In some embodiments, a first angle **465**, for example, in the X-axis, may be larger than a second angle **467**, for example, in the Y-axis. In one embodiment, first angle **465** may be from about 2 degrees to about 5 degrees and second angle **467** may be from greater than 0 degrees to about 3 degrees. In another embodiment, first angle **465** may be about 3 degrees and second angle **467** may be about 1 degree. In exemplary embodiments, angle **455** of wedge adapter plate **450** may be the same as angle **465**.

[0051] Compliance assembly **500** (**FIGS. 9-11**) may include, for example, at least one first portion **502** and at least one second portion **504**. In exemplary embodiments, first portion **502** may define a compliance device **502** for accommodating a positional error between a target location and an actual location. The compliance device may include at least one pressure body **510** associated with, for example, a compliance plate **512** that may be capable of at least three degrees of freedom relative to pressure body **510**. In exemplary embodiments, the three degrees of freedom (see **FIG. 15**) may include freedom to translate along an X-axis and along a Y-axis, and to translate along combinations of the X and Y-axes, and freedom to rotate about a Z-axis at any lateral location. Compliance plate **512** may also be capable of receiving second portion **504**, for example, and transferring the three degrees of freedom to second portion **504**. Pressure body **510** may be suitable for attaching to one of compound adapter plate **460**, wedge adapter plate **450** and manifold adapter plate **440**.

[0052] Second portion 504 may define at least one compliance device adapter 504 for interfacing between compliance plate 512 and at least one glass article. The compliance device adapter may include at least one mounting plate 530 for mounting to compliance plate 512, at least one vacuum body 520 in communication with mounting plate 530 and at least one suction cup being associated with the at least one vacuum body, at least one Z-axis standoff 540 associated with mounting plate 530, at least one compression spring 542 about Z-axis standoff 540, and at least one shim spring 550 associated with both Z-axis standoff 540 and vacuum body 520. In exemplary embodiments, at least a portion of compliance device adapter 504 may be capable of at least three other degrees of freedom; for example, vacuum body 520 may have three other degrees of freedom relative to mounting plate 530. The three other degrees of freedom may include, for example, Z-axis translation, pitching about an X-axis and rolling about a Y-axis (see FIG. 15).

[0053] Z-axis standoff 540, in exemplary embodiments, may stand between mounting plate 530 and vacuum body 520. Z-axis standoff 540 furthermore may connect to mounting plate 530 and to shim spring 550, for example, by a fastener 544. Z-axis standoff 540 may be disposed within bore 524 of vacuum body 520. Bore 524 may have a larger inner width than an outer width of Z-axis standoff 540, resulting in a loose fit between bore 524 and Z-axis standoff 540. In exemplary embodiments, the loose fit of Z-axis standoff 540 to bore 524 may permit motion, for example, lateral or pivotal, of Z-axis standoff 540 within bore 524. In exemplary embodiments, shim spring 550 may be secured to vacuum body 520 by fasteners 552, for example, so that shim spring 550 is held fast to vacuum body 520 at fastener 552 locations. Z-axis standoff 540, being disposed through bore 524, may be attached to shim spring 550 a radial distance from fasteners 552 such that shim spring 550 may flex and twist at Z-axis standoff 540 attachment points, enabling motion, for example, Z-axis translation, pitching and rolling, and of Z-axis standoff 540 relative to vacuum body 520. In exemplary embodiments, a plurality of Z-axis standoffs, for example, three, may be used to generally hold vacuum body 520 a nominal distance from mounting plate 530. Compression springs 542 disposed about Z-axis standoffs 540, when not being acted upon by any outside influence, may generally keep vacuum body 520 the nominal distance from mounting plate 530, but provide additional support for Z-axis translation, pitching and rolling.

[0054] Compliance device 510 may be in fluid communication with a closed pneumatic system (FIG. 7), for example, pressurized air or gas, for activating compliance device 510.

Compliance device 510 may be any such suitable, commercially available compliance device as, for example, from RAD - Robotics & Automation Tooling, Tipp City, OH, USA. The closed pneumatic system may include a pressure source, for example, a pump, that may include a pressure hose assembly 470 in communication with compliance device 510. The closed pneumatic system may be adapted to provide a positive fluid pressure greater than ambient pressure and a negative fluid pressure less than ambient pressure,, e.g, pulling a partial vacuum, for activating the three degrees of freedom of compliance device 510. The three degrees of freedom, in exemplary embodiments, occur when the compliance device 510 is in a depressurized state. Compliance device 510 may have zero degrees of freedom when the pressure body is in a pressurized state. Put another way, under pressure compliance device 510 "locks" or centers compliance adapter plate 512 to a home position, and under a partial vacuum compliance adapter plate 512 maybe free to move in the three degrees of freedom.

[0055] In exemplary embodiments, vacuum body 520 defines a mounting portion, for example, a flange for attaching to compliance adapter 530, and a fitting extension 522 extending orthogonally from the flange. Fitting extension 522 may be adapted to receive a suction cup fitting 526, which in turn may receive a suction cup 560 at an opening 564. Suction cup 560, in exemplary embodiments, may actually contact the glass article for picking and placing onto, for example, mold 214. Vacuum body 520 may include a vacuum passage extending through, for example, the mounting portion and fitting extension 522, the vacuum passage being in fluid communication with the suction cup at fitting extension 522 and at least one hose assembly 470 (FIG. 8) at a periphery of the mounting portion.

[0056] Furthermore, hose assembly 470 may be in fluid communication with manifold 410 for providing the partial vacuum to vacuum body 520. Hose assembly 470 may be made from a heat resistant and pliable elastomer, and in exemplary embodiments may not affect the degrees of freedom of compliance assembly 500. Put another way, hose assembly 470 may move freely along with any movement of any portion of compliance assembly 500 without impeding such movement. To assist in shielding heat from mold pivot table 290 or continuous glass molding system 100, heat shields 490 may be applied substantially below the majority of compliance assembly 500 and manifold 410 (FIGS. 7 and 14), with apertures therein to allow suction cups 560 access for picking and placing. The apertures may be large enough to permit any movement of any portion of compliance assembly 500 and still provide heat resistance

from the high temperatures of mold pivot table 290 or continuous glass molding system 100, and may be made from highly polished metal, for example, stainless steel.

[0057] System 300 may further include input and output nests suitable for receiving, in turn, glass articles before thermal reforming and after thermal reforming (**FIGS.** 19-21). Input and output nests may be located on, for example, input table 330 and output table 320, respectively (see **FIG.** 3). In exemplary embodiments, nests 700 may be structurally identical, being made from different materials. Input nest 700 may include a metallic frame 710, for example, made from an aluminum or steel, having a surface for receiving at least one input receiving frame 720 having at least one input cross bar 730. Input receiving frame 720 and input cross bar 730 may be made from a polymer having a hardness less than that of the glass article so as to not scratch or otherwise damage the glass article. In exemplary embodiments, input receiving frame 720 and input cross bar 730 may be made, for example, from Ultra High Molecular Weight Polyethylene (UHMW).

[0058] In exemplary embodiments, output receiving frame 720 and output cross bar 730 may be made from a soft yet heat resistant material so as not to thermally shock the hot glass articles being placed thereon directly from the hot mold pivot table 290, for example. Output receiving frame 720 and output cross bars 730 may be made, for example, from graphite. Metallic frame 710 may have a bottom for attaching to tables 320, 330, and a top generally opposite the bottom having the same compound angle as compound angle adapter plate 460. At least one reference pin 712 may extend orthogonally from the top surface and may protrude through reference pin apertures 722 located around receiving frame 720, generally extending above the top surface of receiving frame 720. Cross bars 730, generally cylindrically shaped, extend through cross bar apertures 724 located generally on the sides of receiving frame 720. Nests 700 generally include a large amount of open space to allow any broken glass articles to fall through with assistance from a downward vertical laminar airflow, keeping the surfaces clean and free from debris for protecting the glass articles.

[0059] System 300 may cooperate with continuous glass molding system 100 or pivoting mold table 290 in a method of picking and placing an article, for example, at least one glass article being at least one member of the group consisting of a glass plate, a glass preform and a 3-dimensionally shaped glass article, and combinations thereof. In exemplary embodiments, robot 312 may position end effector 400 over input table 330 such that suction cup 560 may be positioned generally over a centroidal region of the glass article. In some embodiments,

robot **116** may position compliance assembly **500** over the centroidal region of the glass article. The compound angles of input nests **700** may be generally matched by the compound angle of compound adapter plate **460**. Input and output nests **700**, as well as, for example, mold **214**, may use the compound angles to encourage the glass articles to nestle against the respective reference pins, which may be located on the "low" sides of the respective compound angles, keeping the glass articles in generally the same location on nests **700** and mold **214**. The position of suction cup **560** over the input glass article maybe from 1 to 5 millimeters above the glass article surface. Once in position the vacuum may be activated, causing the glass article to attach to a mouth region **562**. In exemplary embodiments, end effector **400** may pick at array of glass articles, for example, up to 6 in a front row and up to 6 in a back row. Wedge adapter plate **450** may enable the picking and placing of the front array and the back array independently (see **FIGS. 17 and 18**). Robot **312** may tilt end effector **400** at angle **401** to accommodate the shape of wedge adapter plate **450**, bringing the at least one compliance assembly **500**, located on front of manifold **410**, into general normal alignment with, for example, a mold **610** located on at mold table **292 (FIG. 17)**, keeping the rear array of compliance assemblies **500** above and clear of the rear array of molds. In the case of molds **610** located on mold pivot table **290**, the compound angles may be arranged to cause molds **610** to be angled toward one another. After picking the first array of glass articles end effector **400** may be readjusted to another angle, for example, angle **402**, bringing the at least one compliance assembly **500**, located on the rear of manifold **410**, into generally normal alignment with another mold **610**, lifting the front array of compliance assemblies **500** clear of the other array of molds.

[0060] In some embodiments, robot **312** may move end effector **400** having picked the glass articles from input table **330** into position over mold pivot table **290**. In other embodiments, robot **116** may move compliance assembly **500** having picked a glass article from loading area **118**. End effector **400** may move in a single axis for locating the at least one article to a preheating location proximate to the second location, for example, mold **214** or mold **610**. The preheating location may be substantially above molds **214, 610**.

[0061] Preheating the at least one glass article, in exemplary embodiments, may raise the temperature of the glass article to a temperature closer to the mold temperature to reduce the chance for thermal shock to the glass article when the article is placed on mold **214**. The glass article maybe suspended proximal, for example, about 15 millimeters above mold **214**, and

held in the path of at least one stream of heated gas. The gas, for example, nitrogen (N₂), may be heated by travelling through hot mold **214**, for example, through at least one aperture, where the gas is heated and allowing the at least one stream of heated gas to flow across at least a portion of the at least one glass article.

[0062] The offset positions may be defined by relative coordinates {X, Y, Z} in millimeters (mm) with reference to, for example, the receiving surface of mold **610** and reference pins **620** (see **FIG. 25**) extending from the receiving surface, as related to corresponding edges of the glass articles and the bottom surface of the glass articles. In exemplary embodiments, location **630** may define two locations that share X-axis and Y-axis coordinates: the preheating location {2.5, 2.5, 15}, and a pre-placement location {2.5, 2.5, 2}. Robot **312** may move end effector **400** at a pre-placement velocity, for example, about 200 millimeters per second (mm/s) to move the glass article downward from the preheating location **630** to pre-placement location **630**. Pre-placement location **630** may define a first article offset distance in the X-axis of about 2.5 mm and a second article offset distance in the Y-axis of about 2.5 mm, both from the at least one reference pin **620**, and further define a third article offset distance in the Z-axis of about 2 mm from the receiving surface of mold **610**.

[0063] Robot **312** may move end effector **400** laterally to position **632**, for example, in a diagonal motion to reassign the X and Y coordinates, defining a base placement location **632** having relative coordinates {1, 1, 2}. This lateral, diagonal motion may be at another velocity, for example, about 50 mm/s, with the heated gas continuing to flow around the glass article.

[0064] Robot **312** may move in all three axes at a third velocity, for example, 30 mm/s, to a final location prior to placing the glass article, location **634**. Location **634** may define an overdrive location **634**. The glass article may have relative coordinates {0, 0, 0.5} at location **634**, e.g., the glass article maybe touching reference pins **620** on at least two edges of the glass article, leaving the glass article suspended above the receiving surface of mold **610** at a fourth offset distance in the Z-axis of about 0.5 mm. The combination of the three degrees of freedom and the three other degrees of freedom provide for 6 degrees of freedom for suction cup **560**, for example, relative to manifold **410** (see **FIG. 16**). At the point when the glass article contacts the reference pins **620** in the X and Y axes, the end effector **400** continues its movement for an additional distance in X and Y, ending at the overdrive location **634**, for example, {-1, -1, 0.5}. When one of the glass articles makes contact with the reference pins **620**, compliance assembly **500**, having 6 degrees of freedom, allows end effector **400** to

continue the movement while not damaging the glass article. This provides for differences in the relative location of the array of molds **610** due to thermal expansion, and insuring that all of the glass articles in the arrays are placed correctly, while not damaging any of the glass articles. Put another way, the step of moving end effector **400** in at least three axes simultaneously may include moving end effector **400** in the X-axis, the Y-axis and the Z-axis simultaneously, end effector **400** moving toward the at least one locating reference feature, for example, reference pins **620**, by an amount greater than the first offset distance in the X-axis and an amount greater than the second offset distance in the Y-axis, and an amount less than the third offset distance in the Z-axis.

[0065] By shutting off the vacuum supply, the glass articles are allowed to freely descend along the fourth offset distance, placing the glass article along side the receiving surface with a gap between the glass article and the receiving surface, the gap defining a bearing layer of the heated gas. The bearing layer of heated gas may control a thermal gradient as observed by thermal imagery as the glass article heats to an operable thermal reforming temperature (see **FIGS. 26A-28C**), which will be discuss later in the disclosure.

[0066] After thermal reforming has been completed, as discussed previously, the hot 3D glass articles may be picked from mold **610** and placed on output table **320**. The heated gas may be reinitiated, causing the hot 3D glass articles to "jump" and separate from the mold profile surface, and begin to cool. Compliance device **510** may be locked during the pick up operation by reapplying the positive pressure. End effector **400** may be repositioned above the hot 3d glass articles by moving end effector **400** toward the 3D glass article in the Z-axis so compliance assembly **500**, for example, may be vertically offset from the glass article by a fifth offset distance, for example, about 2 mm. By reapplying the at least one fluid pressure, for example, the vacuum, to vacuum body **520**, the glass articles, already substantially floating on another bearing layer of heated gas, may ascend the fifth offset distance, effectively leaping to meet mouth portion **562** of suction cup **560**, thereby picking the hot 3D glass articles from the second location. Robot **312** may then move end effector **400** toward a third location, for example, output table **320**, placing the glass article at the third location, for example, positioning the glass articles slightly above, for example, at a output nests **700** and releasing the glass articles to drop to output receiving frame **720, 740**.

[0067] A method of controlling the observable thermal gradient across the glass article includes, for example, limiting physical contact with the receiving surface, for example,

floating the glass article on the heated gas bearing layer, causing the glass article to heat from the outside inward rather than from the inside outward. Heating from the inside outward may cause an unacceptable rate of thermal shock to the glass articles, damaging or destroying the glass articles. Thermal images **800A**, **800B** and **800C** represent a glass article heating on a hot mold without benefit of a bearing layer of heated gas, and thermal images **900A**, **900B**, and **900C** represent another glass article heating on a hot mold with benefit of a bearing layer of heated gas. For example, regarding thermal image **800A**, perimeter regions **810**, **812** are generally cooler than middle region **814** (**FIG. 26A**) as evidenced by scale **1000A** (**FIG. 26C**). Hottest region **1002** maybe seen in middle region **814**, while coolest region **1001** maybe seen in perimeter regions **810**, **812**. Image **900A** (**FIG. 26B**) represents heating of the glass article having benefit of the bearing layer of gas, hottest region **1002** may be seen in perimeter region **912**, with perimeter region **910** being hotter than middle region **914**.

[0068] Regarding thermal image **800B**, perimeter regions **820**, **822** are generally cooler than middle region **824** (**FIG. 27A**) as evidenced by scale **1000B** (**FIG. 27C**). Hottest region **1004** may be seen in middle region **824**, while coolest region **1003** may be seen in perimeter regions **820**, **822**. Image **900B** (**FIG. 26B**) represents continued heating of the glass article having benefit of the bearing layer of gas, hottest region **1004** being seen in perimeter region **922**, with perimeter region **920** being hotter than middle region **924**.

[0069] Regarding thermal image **800C**, perimeter regions **830**, **832** are generally cooler than middle region **834** (**FIG. 28A**) as evidenced by scale **1000C** (**FIG. 28C**). Hottest region **1006** may be seen in middle region **834**, while cooler region **1005** being seen in perimeter regions **830**, **832**. Image **900C** (**FIG. 26B**) represents heating of the glass article having benefit of the bearing layer of gas, hottest region **1004** being seen in perimeter region **932**, with perimeter region **930** being hotter than middle region **934**.

[0070] 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 disclosure. Thus it is intended that the present disclosure 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. A system for handling a glass article that is being transported to and from a thermal reforming apparatus, comprising:

at least one robot;

at least one input nest assembly, the input nest assembly including at least one input cross bar receiving frame, at least one input cross bar for inserting into the at least one input cross bar receiving frame and at least one compound angle nest frame for receiving the at least one input cross bar receiving frame, the at least one input cross bar receiving frame and at least one input cross bar comprising a polymer;

an output nest assembly, the output nest assembly including at least one output cross bar receiving frame, at least one output cross bar for inserting into the at least one output cross bar receiving frame and another of the at least one compound angle nest frames for receiving the at least one output cross bar receiving frame, the at least one output cross bar receiving frame and at least one output cross bar comprising a heat resistant material;

a manifold, the manifold having at least one connecting means for connecting the manifold to the robot, at least one adapter plate and at least one chamber;

at least one wedge adapter plate;

at least one compound angle adapter plate, the at least one compound angle adapter plate having a compound angle that corresponds to the at least one compound angle nest frame;

at least one open pneumatic system, the at least one open pneumatic system adapted to apply a fluid pressure that is lower than an ambient pressure through the at least one chamber, creating a partial vacuum in the at least one chamber;

at least one closed pneumatic system, the at least one closed pneumatic system adapted to apply another fluid pressure, the other fluid pressure including a positive fluid pressure greater than the ambient pressure and a negative fluid pressure less than the ambient pressure;

at least one compliance assembly, the compliance assembly including at least one first portion in fluid communication with the at least one closed pneumatic system, and at least one second portion in fluid communication with the at least one open pneumatic system, the at least one first portion comprising a compliance device for accommodating a positional error between a target location and an actual location, at least a portion of the compliance device

capable of at least three degrees of freedom, and the at least one second portion comprising a compliance device adapter for interfacing between the compliance device and at least one glass article, at least a portion of the compliance device adapter capable of at least three other degrees of freedom.

2. The system of claim 1, the system cooperating with a thermal reforming apparatus for thermally reforming the glass article from a first shape to a second shape, the thermal reforming apparatus including at least one heating system and at least one mold.

3. The system of claims 1 or 2, the at least one mold including a receiving surface and a second-shape profile surface.

4. The system of claim 3, the second-shape profile surface corresponding to the second shape of the at least one glass article, and further including at least one port through the second-shape profile surface, the at least one port being suitable for applying a vacuum to draw the glass against the second-shape profile surface during a thermal reforming process.

5. A robot end effector for picking and placing a glass article, comprising:
at least one compliance assembly, the compliance assembly including at least one first portion defining at least one compliance device, the at least one compliance device having a pressure body and at least one compliance plate, the at least one compliance plate capable of three degrees of freedom relative to the pressure body, the pressure body being in communication with a robot arm, and at least one second portion defining a compliance device adapter, the compliance device adapter suitable for interfacing between the compliance device and at least one glass article, the compliance device adapter including at least one mounting plate for mounting to the compliance device, at least one vacuum body in communication with the at least one mounting plate and at least one suction cup being associated with the at least one vacuum body, at least a portion of the compliance device adapter capable of at least three other degrees of freedom.

6. The end effector of claim 5, the second portion including at least one Z-axis standoff being associated with the at least one mounting plate, at least one compression spring about

the at least one Z-axis standoff, and at least one shim spring associated with the at least one Z-axis standoff and the at least one vacuum body.

7. The end effector of claim 5, the three degrees of freedom including freedom to translate along an X-axis and along a Y-axis, and to translate along combinations of the X and Y-axes, and freedom to rotate about a Z-axis at any lateral location.

8. The end effector of claims 5 or 7, the three degrees of freedom occurring when the pressure body is in a depressurized state, the at least one compliance plate having zero degrees of freedom when the pressure body is in a pressurized state.

9. The end effector of claim 5, the vacuum body having the three other degrees of freedom relative to the at least one mounting plate.

10. The end effector of claims 5 or 9, the three other degrees of freedom including freedom to pitch about an X-axis, freedom to roll about a Y-axis and freedom to translate along a Z-axis.

11. The end effector of claim 5, the vacuum body including a mounting portion and a fitting extension extending orthogonally from the mounting portion, the vacuum body further having a vacuum passage extending through the mounting portion and the fitting extension, the vacuum passage being in fluid communication with the suction cup at the fitting extension and at least one hose assembly at a periphery of the mounting portion.

12. The end effector of claims 5 or 11, further including a manifold, the at least one hose assembly being in fluid communication with the manifold for picking and placing a plurality of glass articles, the manifold having at least one connecting means for connecting the manifold to the robot, at least one adapter plate for receiving the compliance assembly, and at least one chamber, the at least one chamber comprising part of at least one open pneumatic system, the open pneumatic system adapted to apply a fluid pressure that is lower than an ambient fluid pressure through the at least one chamber, creating a partial vacuum in the at least one chamber;

13. The end effector of claim 5, the at least one chamber comprising at least a front chamber and a rear chamber.
14. The end effector of claims 5 or 13, the front chamber being in fluid communication with a front transition chamber, and the rear chamber being in fluid communication with a rear transition chamber, the front transition chamber passing through the rear chamber without being in fluid communication with the rear chamber.
15. The end effector of claim 5, the manifold including at least one inlet port in communication with the at least one chamber, the inlet port further being in communication with the second portion of the compliance assembly by at least one hose assembly connected thereto, the at least one inlet port for allowing fluid flow from the at least one hose assembly to the at least one chamber.
16. The end effector of claims 5 or 15, the manifold including at least one outlet port in communication with the at least one chamber, the at least one outlet further being in communication with at least one vacuum source by at least one vacuum hose connected thereto, the at least one outlet port for allowing fluid flow from the at least one chamber to the at least one vacuum hose.
17. The end effector of any of claims 5, 15 and 16, the manifold including an array of adapter plates for receiving a plurality of compliance assemblies.
18. A method of picking and placing an article, the method comprising the steps of:
positioning an end effector having at least one compliance assembly proximate to at least one article at a first location;
applying at least one fluid pressure to at least one portion of the at least one compliance assembly;
picking the at least one article;

moving the end effector in at least three axes simultaneously toward a second location, the second location having at least one locating reference feature associated with at least one article receiving surface; and

placing the at least one article at the second location.

19. The method of claim 18, further including the step of moving the end effector in a single axis for locating the at least one article to a preheating location proximate to the second location, the preheating location being substantially above the second location.

20. The method of claims 18 or 19, further including the step of moving the end effector in a single axis for locating the at least one article at a pre-placement location, whereby the at least one article is offset from the at least one locating reference feature by a first article offset distance in an X-axis and by a second article offset distance in a Y-axis, and offset from the at least one article receiving surface by a third article offset distance in a Z-axis.

21. The method of claim 20, the first article offset distance being equal to the second article offset distance, and the third article offset distance being greater than the first and second article offset distances.

22. The method of claim 20, the step of moving the end effector in at least three axes simultaneously including moving the end effector in the X-axis, the Y-axis and the Z-axis simultaneously, the end effector moving toward the at least one locating reference feature by an amount greater than the first offset distance in the X-axis, an amount greater than the second offset distance in the Y-axis, and an amount less than the third offset distance in the Z-axis.

23. The method of claim 22, the step of moving the end effector in at least three axes simultaneously including moving the end effector in the X-axis and the Y-axis at a first velocity, and moving the end effector in the Z-axis at a second velocity.

24. The method of claim 22, the step of moving the end effector in at least three axes simultaneously including moving the at least one article along the first offset distance and the

second offset distance causing the at least one article to make contact with the at least one locating reference feature in the X-axis and the Y-axis.

25. The method of claim 22, the step of moving the end effector in at least three axes simultaneously including moving the at least one article along a portion of the third offset distance leaving the at least one article offset from the at least one receiving surface by a fourth offset distance in the Z-axis that is smaller than the third offset distance.

26. The method of claim 25, the step of placing the at least one article at the second location including releasing the at least one article and allowing the at least one article to freely descend along the fourth offset distance for contacting the at least one receiving surface.

27. The method of any of claims 18 - 26, the first location being at least one input nest and the second location being at least one mold.

28. The method of any of claims 18 - 27, further including the steps of:
repositioning the end effector having the at least one compliance assembly proximate to the at least one article at the second location;
reapplying the at least one fluid pressure to the at least one portion of the at least one compliance assembly;
picking the at least one article from the second location;
moving the end effector toward a third location, the third location including at least one output nest; and
placing the at least one article at the third location.

29. The method of claim 28, the step of reapplying the at least one fluid pressure to the at least one portion of the at least one compliance assembly including reapplying the first positive fluid pressure for locking the at least one compliance assembly.

30. The method of claim 29, the step of repositioning the end effector including moving the end effector toward the at least one article in the Z-axis so the compliance assembly is vertically offset from the at least one article by a fifth offset distance.

31. The method of claim 30, the step of reapplying the at least one fluid pressure to at least one portion of the at least one compliance assembly including reapplying the second negative fluid pressure for picking the at least one article.
32. The method of claim 31, the step of picking the at least one article including the at least one article moving vertically and traversing the fifth offset distance in response to the second negative fluid pressure.
33. The method of claim 18, the at least one article comprising a glass article being at least one member of the group consisting of a glass plate, a glass preform and a 3-dimensionally shaped glass article.
34. The method of claim 18, the step of applying the at least one fluid pressure to the at least one portion of the at least one compliance assembly including applying at least one first fluid pressure to a first portion of the at least one compliance assembly, the first portion having a closed pneumatic system for locking and unlocking the at least one compliance assembly.
35. The method of claim 34, the at least one first fluid pressure including a first positive fluid pressure for locking the at least one compliance assembly and a first negative fluid pressure for unlocking the at least one compliance assembly.
36. The method of claim 18, the step of applying the at least one fluid pressure to the at least one portion of the at least one compliance assembly including the step of applying at least one second fluid pressure to a second portion of the at least one compliance assembly, the second portion having an open pneumatic system for picking and placing the at least one article.
37. The method of claim 36, the at least one second fluid pressure being lower than an ambient fluid pressure.

38. The method of claim 37, the open pneumatic system being adapted to apply the at least one second fluid pressure for picking the at least one article, and adapted to withhold the at least one second fluid pressure for placing the at least one article.

39. A method of controlling a thermal gradient across a glass article being in thermal communication with a thermal reforming apparatus, for mitigating thermal shock to the glass article during a thermal reforming process, comprising the steps of:

providing at least one glass article having a first shape, the first shape having a perimeter region and a middle region;

providing a thermal reforming apparatus for shaping the at least one glass article from the first shape to a second shape, the thermal reforming apparatus including at least one mold, the mold having at least one receiving surface and at least one second-shape profile surface;

providing at least one stream of heated gas;

preheating the at least one glass article to a preheat temperature;

placing the at least one glass article along side the receiving surface with a gap substantially between the at least one preheated glass article and the receiving surface, the gap defining a bearing layer of the heated gas; and

controlling a thermal gradient of the at least one glass article as the at least one glass article changes temperature from the preheat temperature to an operable thermoforming temperature by limiting physical contact with the receiving surface, the at least one glass article being hotter toward at least a portion of the perimeter region than the middle region.

40. The method of claim 39, including the step of removing the stream of heated gas to eliminate the bearing layer of the flowing heated gas.

41. The method of claims 39 or 40, including the step of allowing the at least one glass article to directly contact the receiving surface substantially around the perimeter region.

42. The method of any of claims 39 - 41, including the step of performing a thermal reforming process, the thermal reforming process including changing the at least one glass article from the first shape to the second shape in part by applying a vacuum to the mold and

the at least one glass article, causing the at least one glass article to conform to the second-shape profile surface and assume the second shape.

43. The method of any of claims 39 - 42, including the step of inducing the at least one glass article having the second shape to separate from the second-shape profile surface by reapplying the stream of heated gas, causing the at least one glass article having the second shape to float on another bearing layer of heated gas proximal to the second-shape profile surface and limiting physical contact with the second-shape profile surface.

44. The method of claim 43, the thermal reforming apparatus further including at least one port through the second-shape profile surface, the at least one port being suitable for applying a vacuum to draw the glass against the second-shape profile surface, and for applying the stream of heated gas for the bearing layer for controlling the thermal gradient.

45. The method of claim 39, the step of preheating the at least one glass article to a preheat temperature including suspending the at least one glass article proximal to the at least one stream of heated gas and allowing the at least one stream of heated gas to flow across at least a portion of the at least one glass article.

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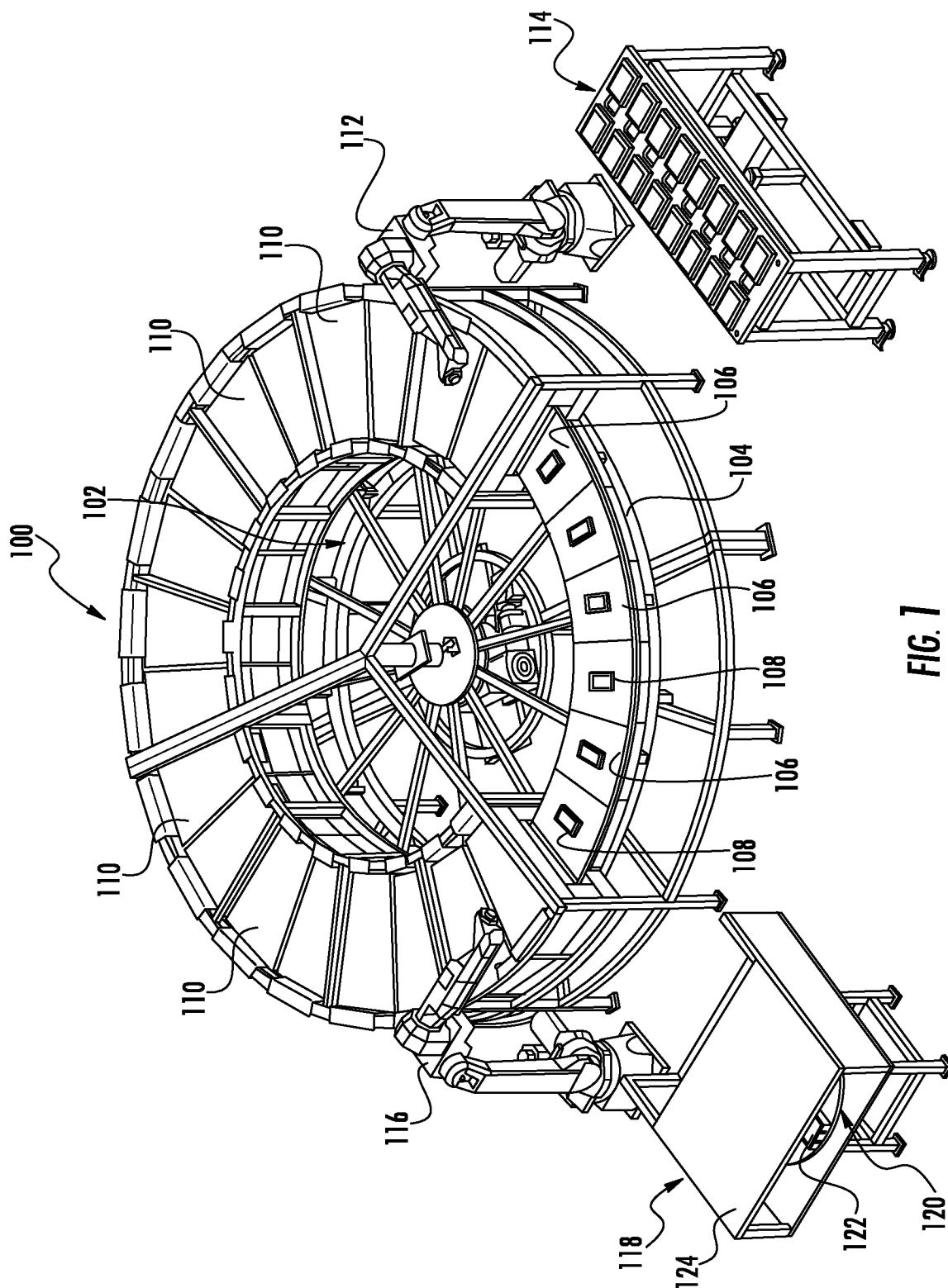


FIG. 1

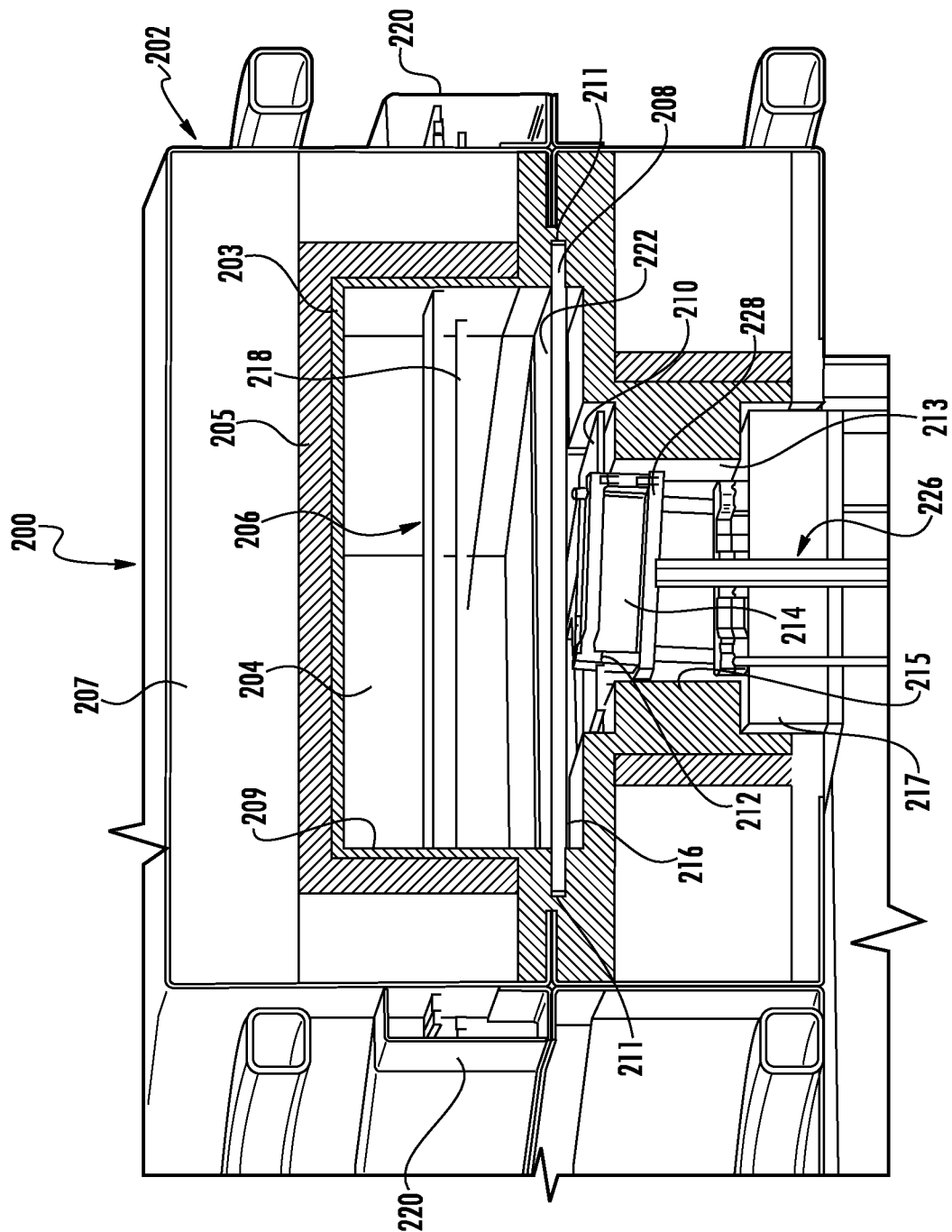
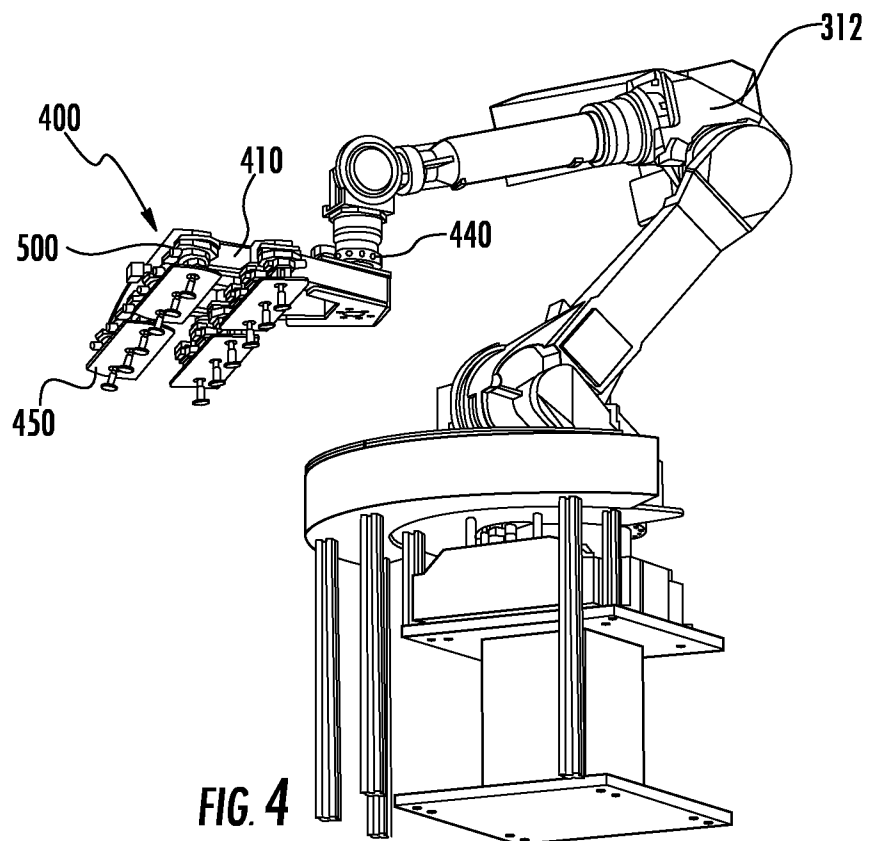
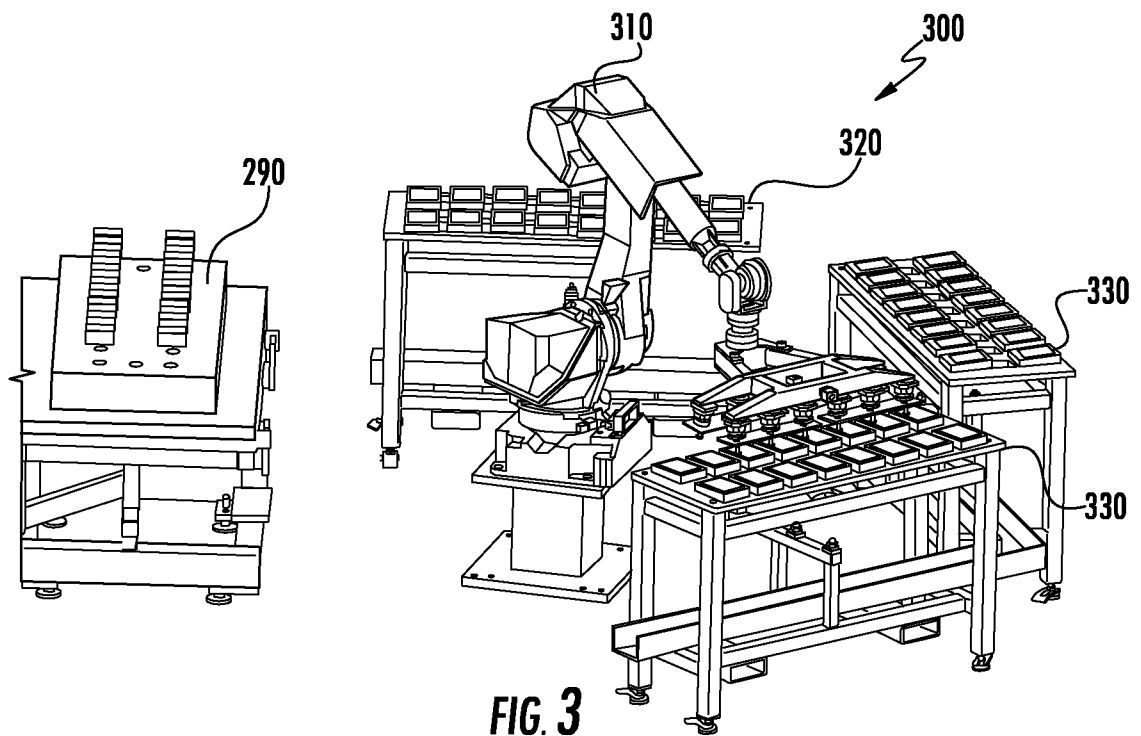


FIG. 2

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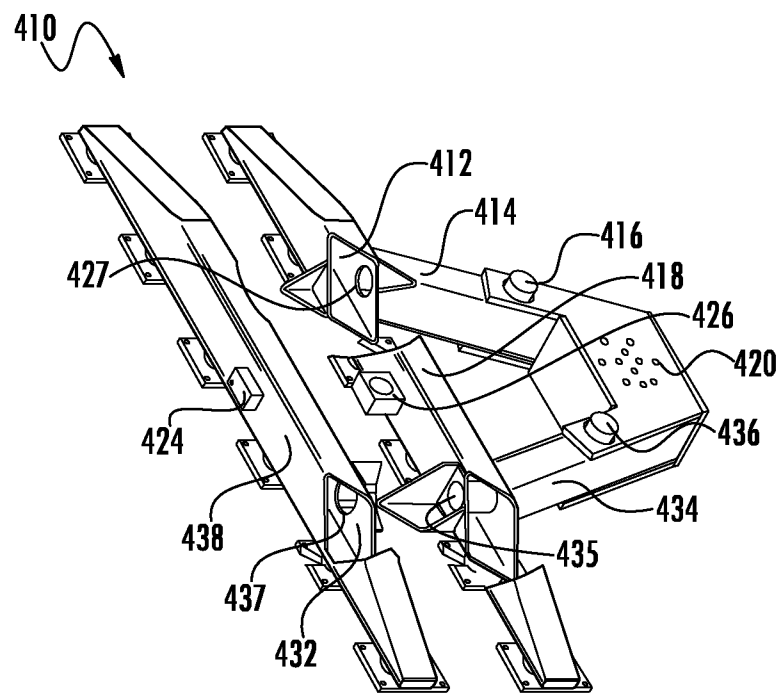


FIG. 5

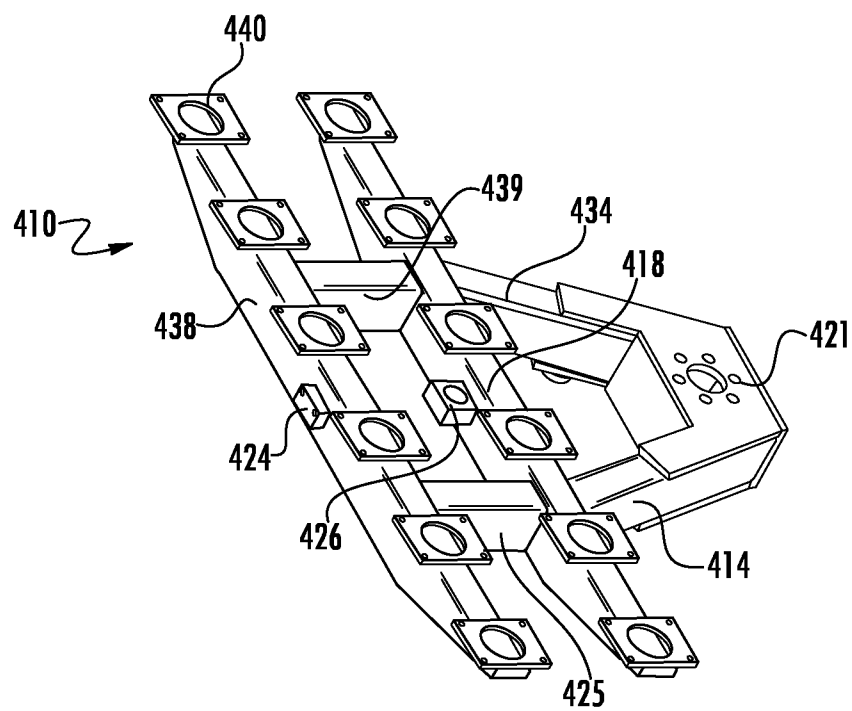
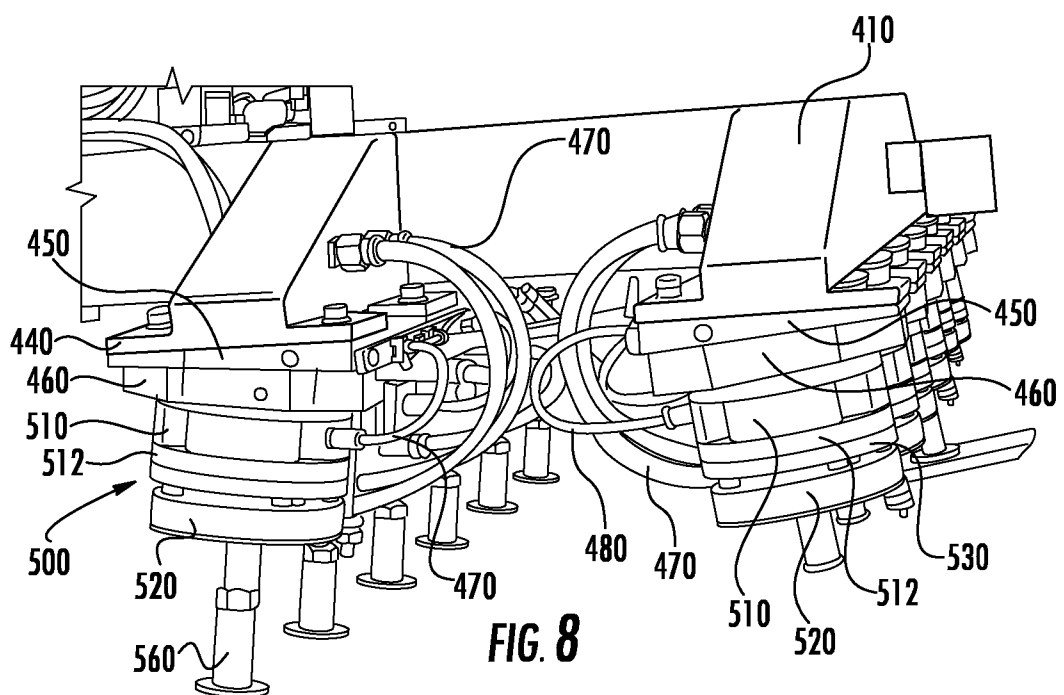
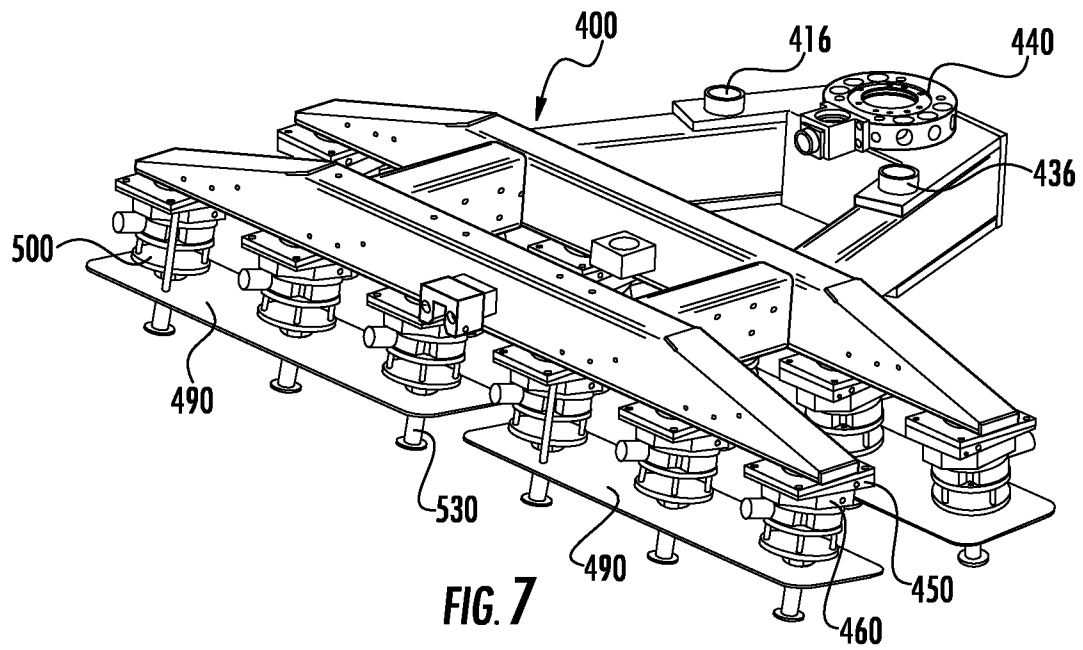


FIG. 6

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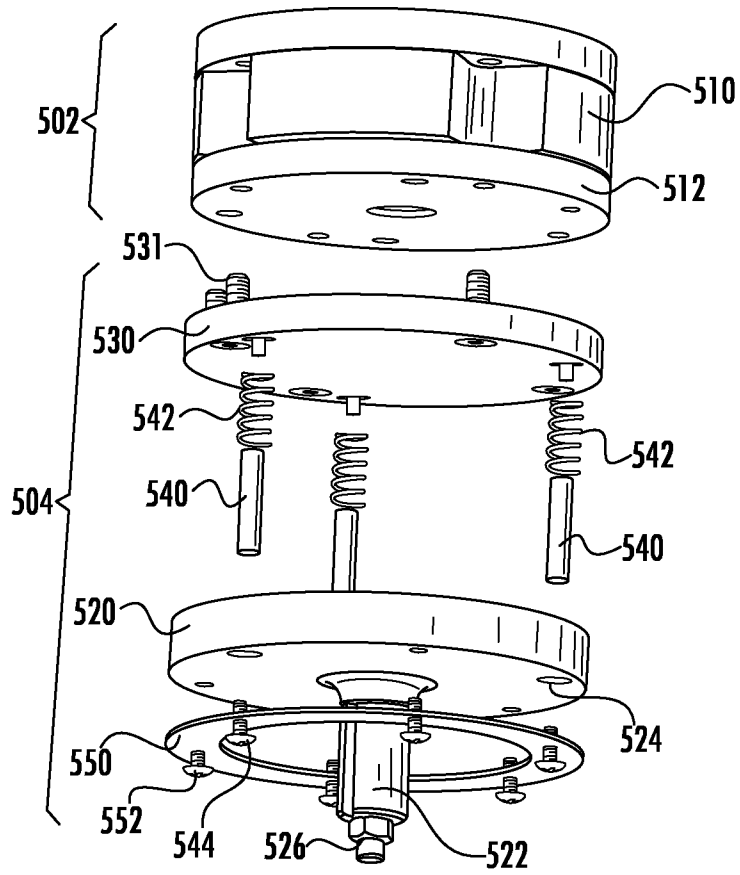


FIG. 9

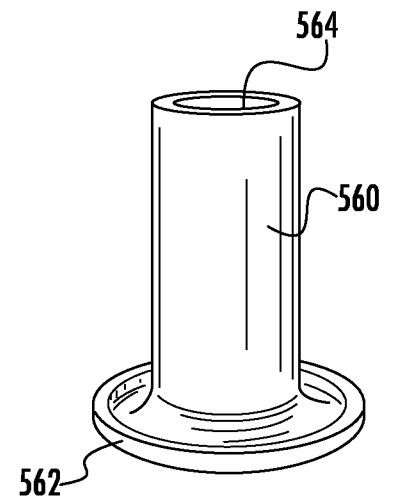


FIG. 10

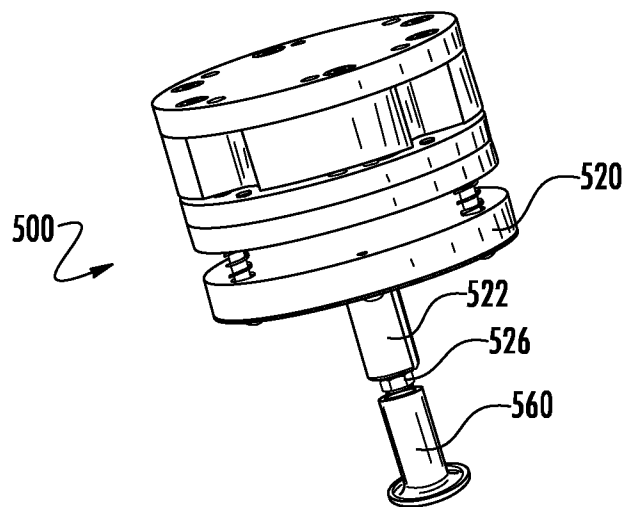
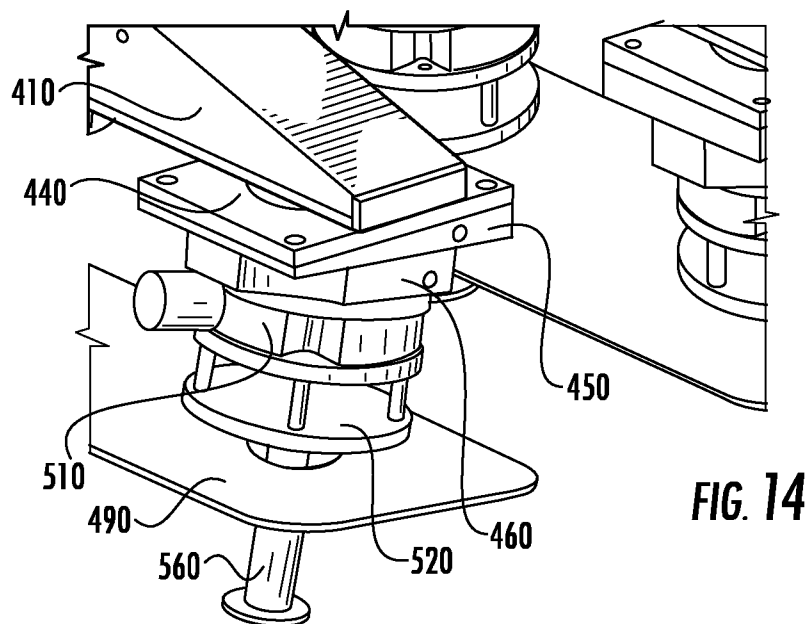
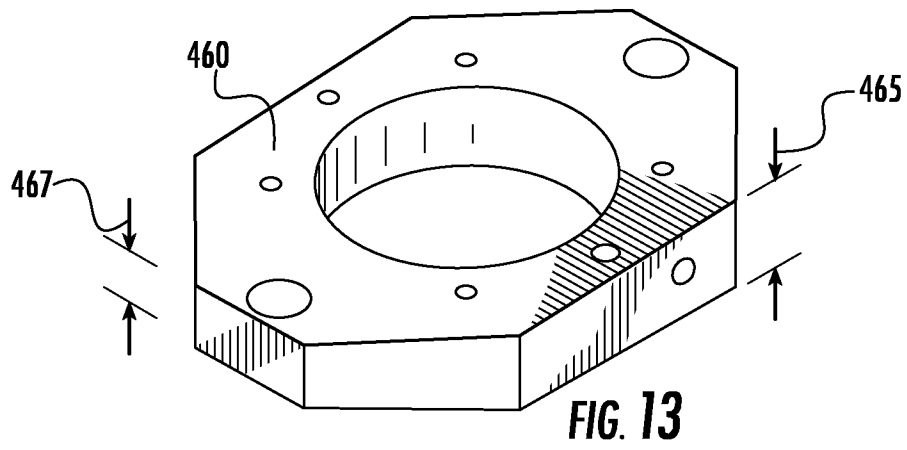
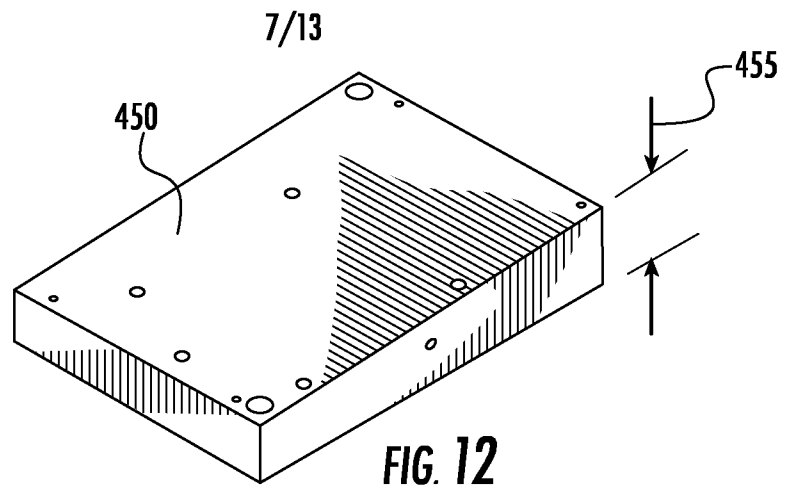
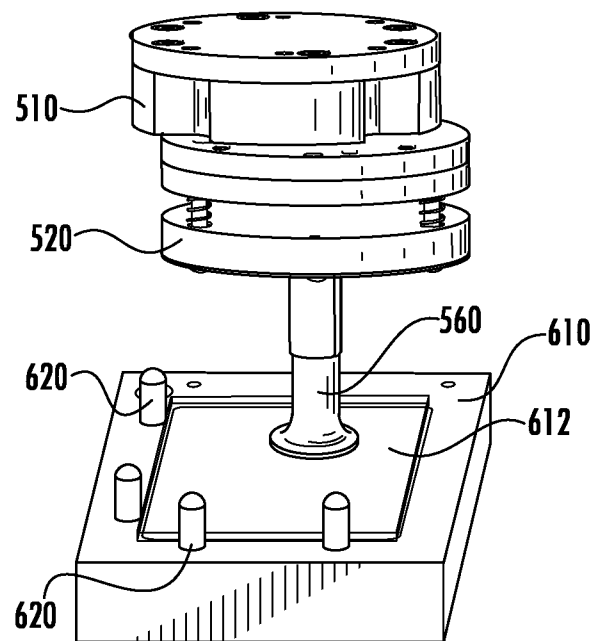
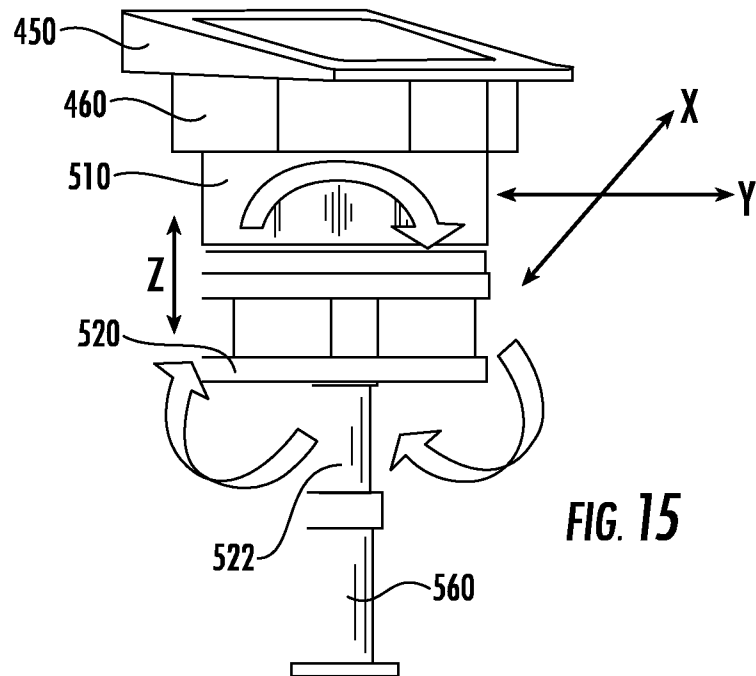


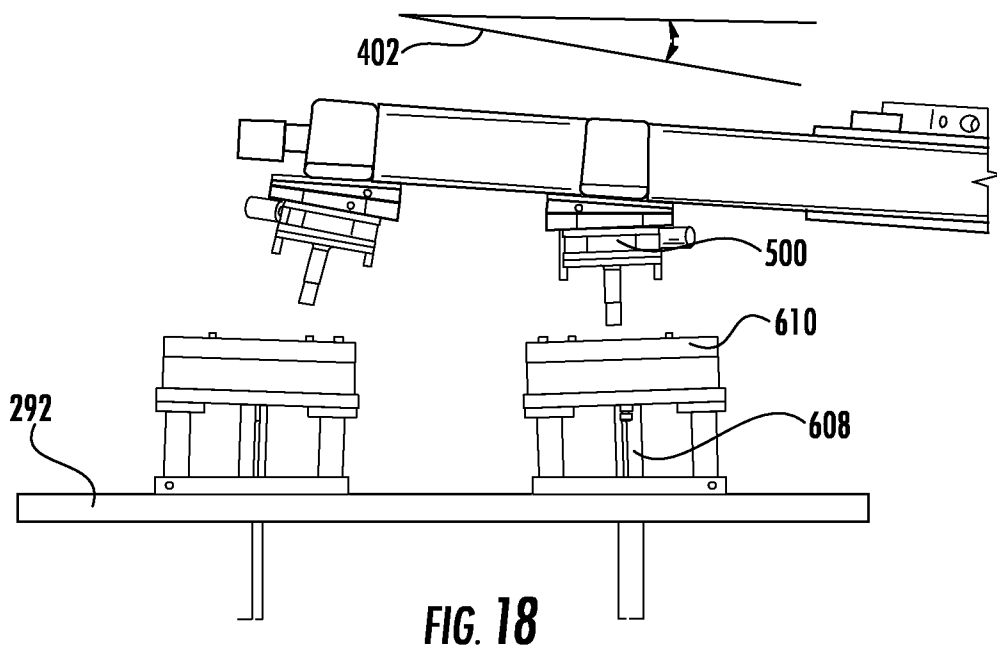
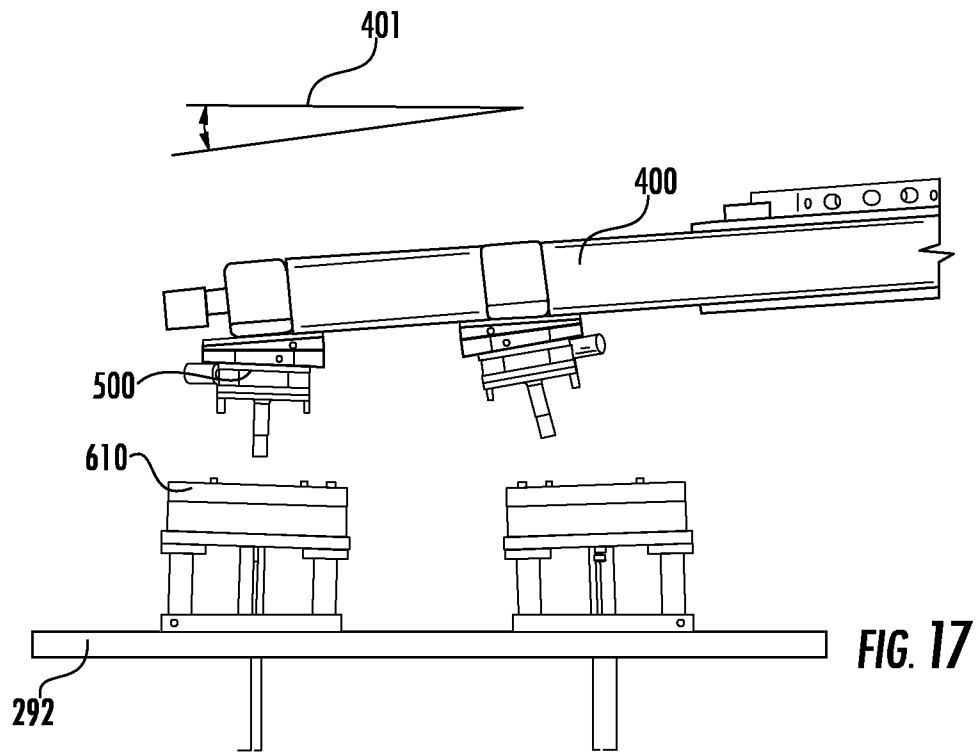
FIG. 11



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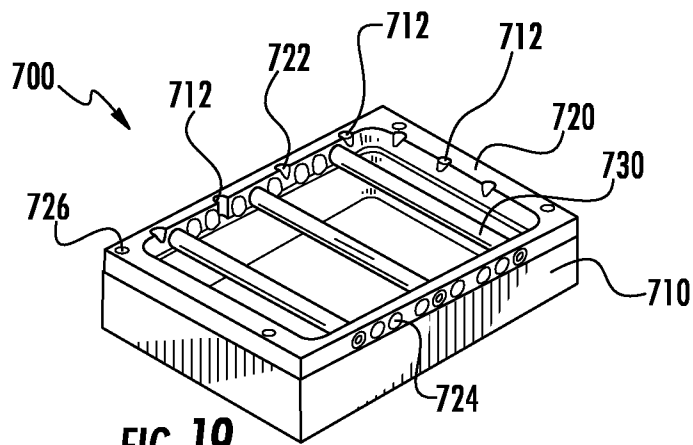


FIG. 19

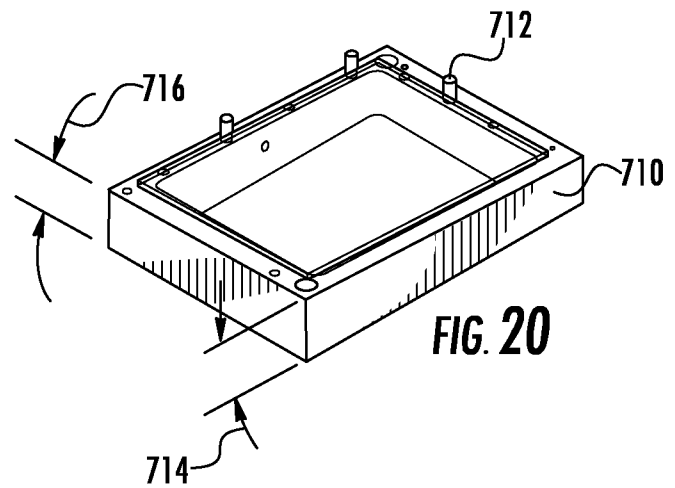


FIG. 20

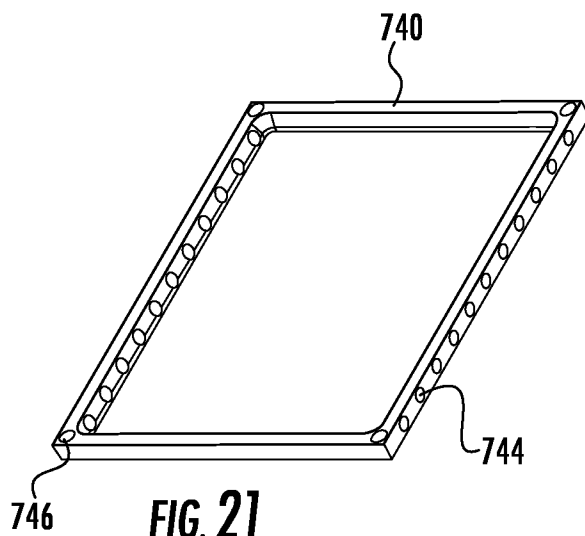


FIG. 21

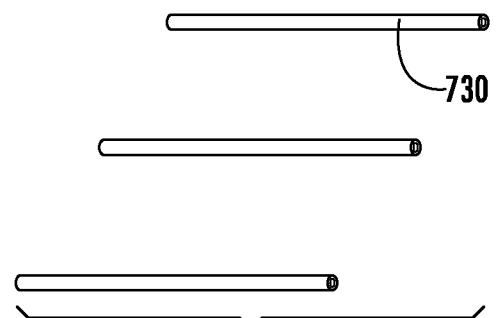
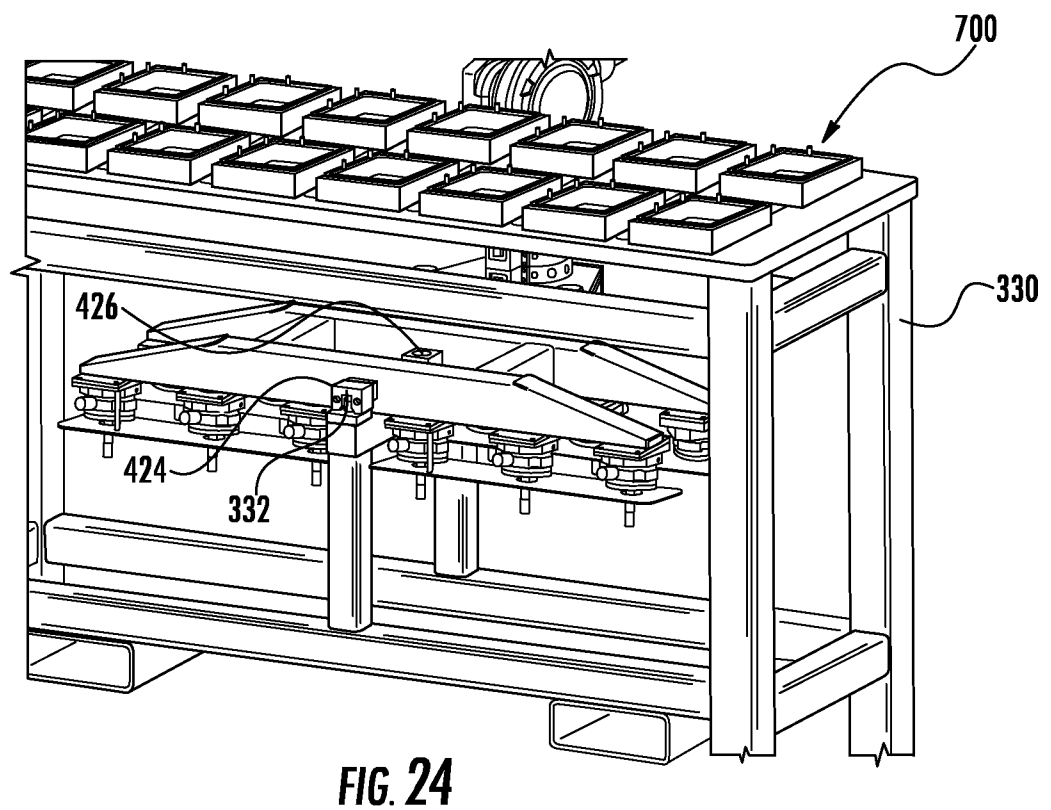
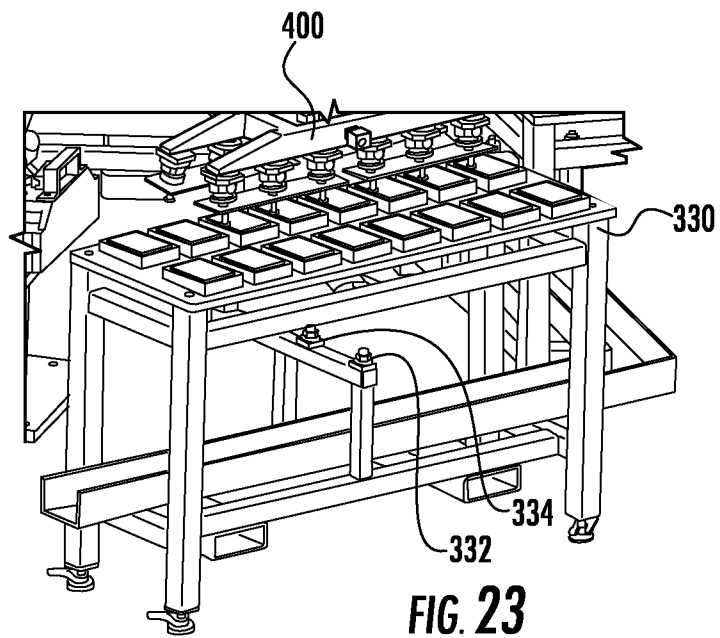


FIG. 22

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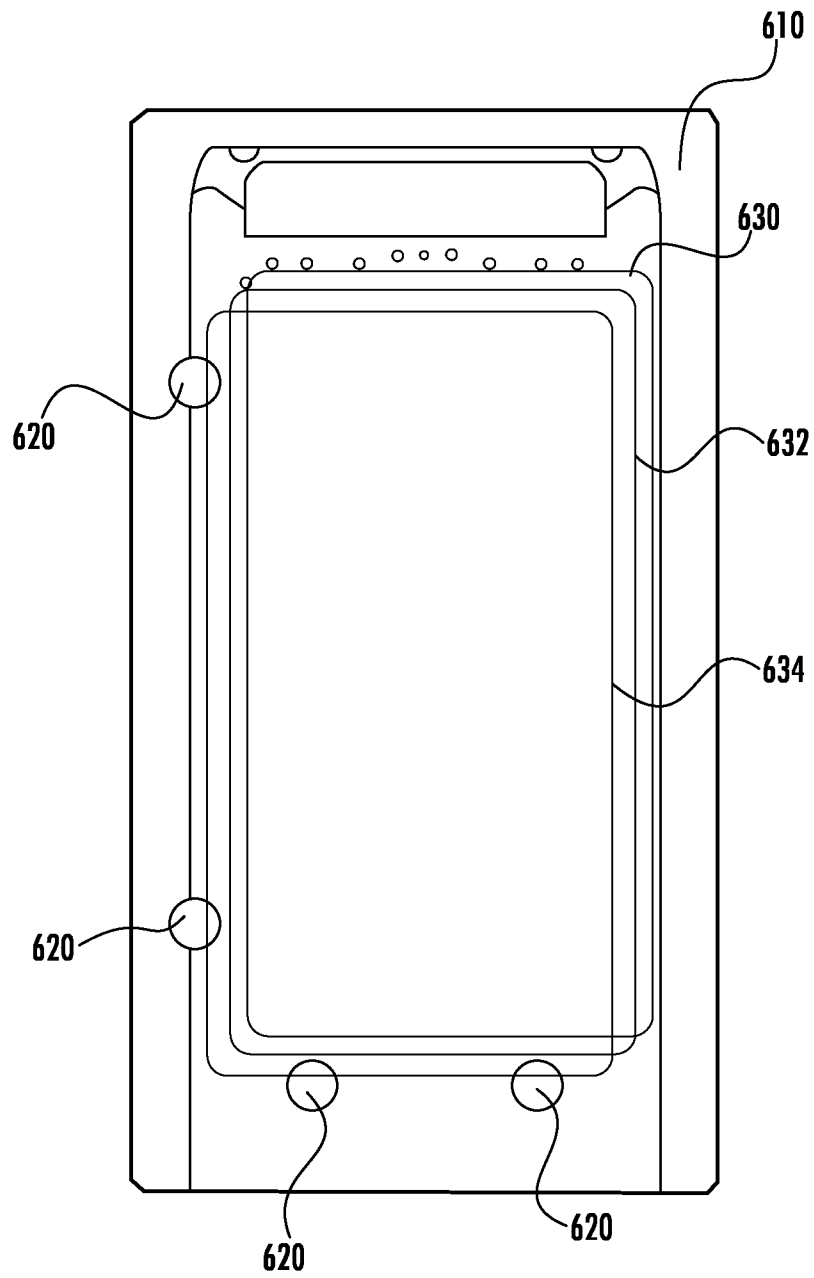


FIG. 25

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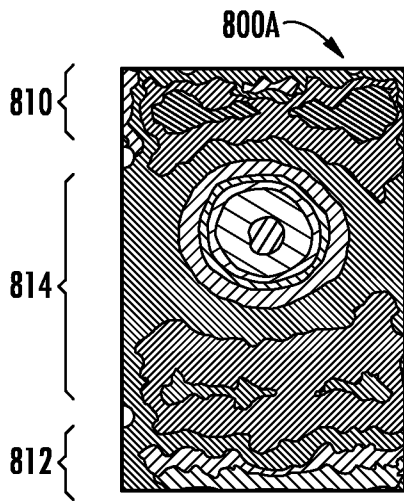


FIG. 26A

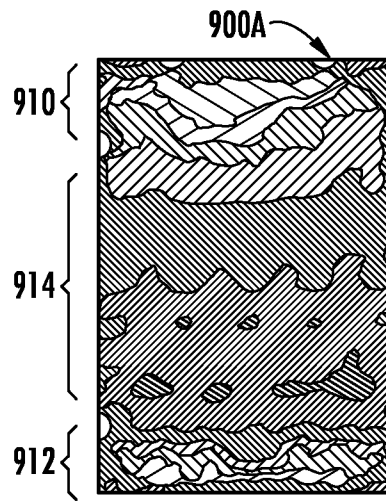


FIG. 26B

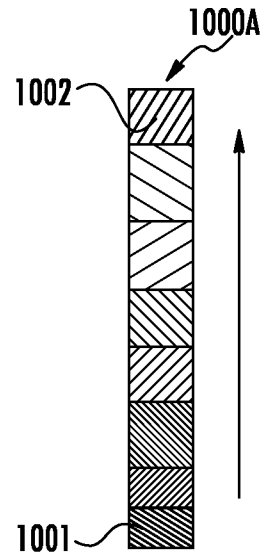


FIG. 26C

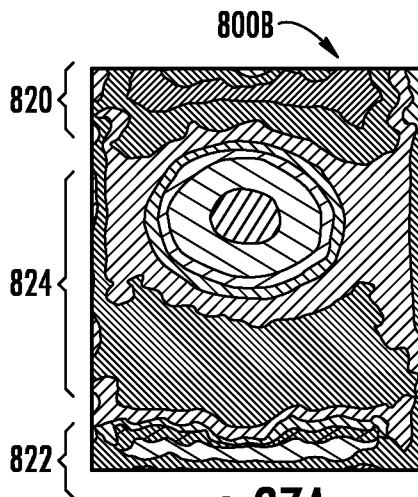


FIG. 27A

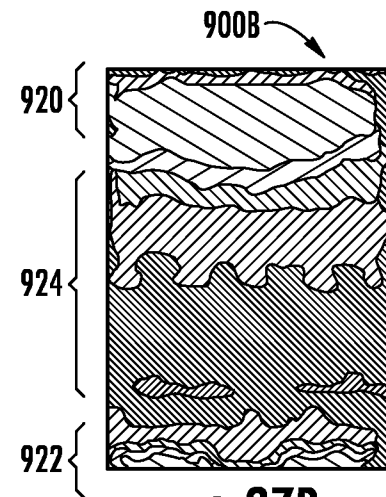


FIG. 27B

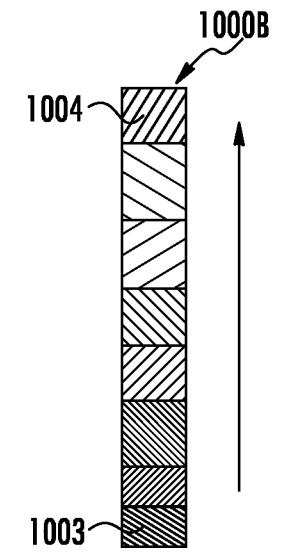


FIG. 27C

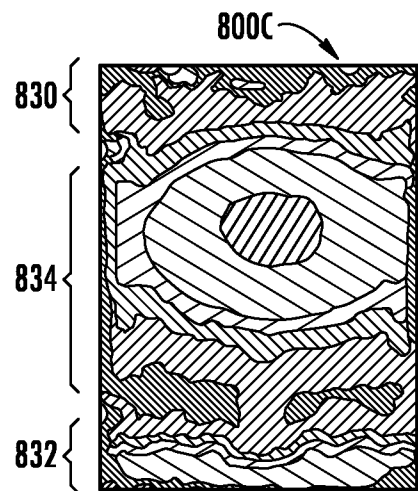


FIG. 28A

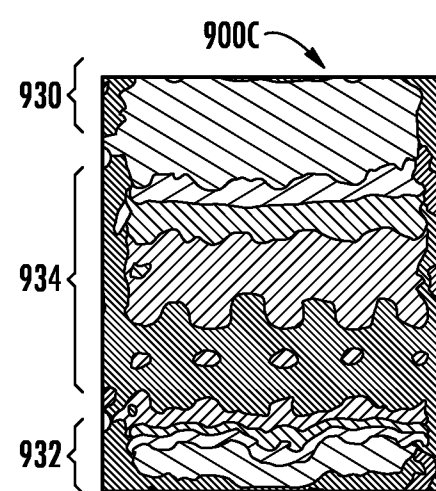


FIG. 28B

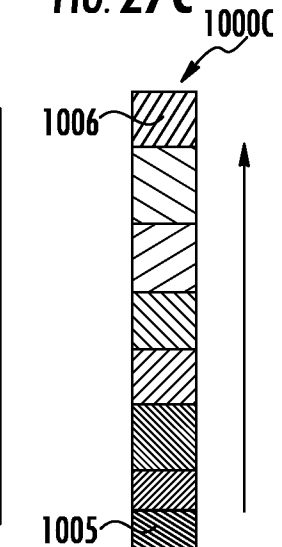


FIG. 28C