(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
06 December 2018 (06.12.2018)

WIPO | PCT

(10) International Publication Number
WO 2018/222408 A1

(51) International Patent Classification:
*B29C 64/124* (2017.01) *B29C 64/223* (2017.01) *B29C 64/357* (2017.01) *B29C 64/00* (2017.01) *B29C 64/245* (2017.01)

(21) International Application Number: PCT/US2018/033201

(22) International Filing Date: 17 May 2018 (17.05.2018)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
15/612,228 02 June 2017 (02.06.2017) US

(71) Applicant: 3D SYSTEMS, INC. [US/US]; 333 Three D Systems Circle, Rock Hill, SC 29730 (US).

(72) Inventor: TANNER, Christopher; 5238 Southhampton Cove, San Diego, CA 92130 (US).

(74) Agent: ROBERSON, Keith; 3D Systems, Inc., 333 Three D Systems Circle, Rock Hill, SC 29730 (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, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, 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, SA, 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, ST, 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, KM, ML, MR, NE, SN, TD, TG).

**Published:**
— *with international search report (Art. 21(3))*

(54) **Title:** THREE DIMENSIONAL PRINTING SYSTEM WITH IMPROVED MACHINE ARCHITECTURE

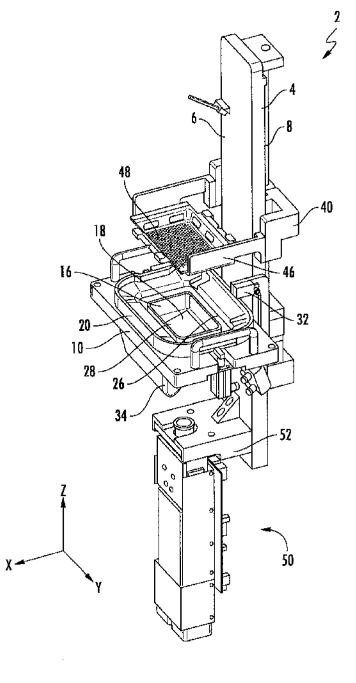


FIG. 1A

**(57) Abstract:** A three dimensional printing system (2) includes a vertical support (4), a support plate (10), a resin vessel (20), a carriage (40), and a support fixture (48). The support plate has a proximal end (12) affixed to the vertical support and extends along a first lateral axis to a distal end (14). The resin vessel is supported by the support plate and has a rear side (22) that is proximate to the proximal end of the support plate. A resin fluid outlet (30) is supported over the rear side of the resin vessel. The carriage is configured to be translated vertically along the vertical support. A pair of fixture receiving arms (46) extend from the carriage along the first lateral axis from a proximal to a distal end. The fixture receiving arms are spaced apart along a second lateral axis that is perpendicular to the first lateral axis. A support fixture (48) is supported by the two fixture receiving arms.

WO 2018/222408 A1

# Three Dimensional Printing System with Improved Machine Architecture

## Field of the Invention

[001] The present disclosure concerns an apparatus and method for fabrication of solid three dimensional (3D) articles of manufacture from radiation curable (photocurable) resins. More particularly, the present invention provides a machine architecture that enhances automation, modularity, and reliability to enhance the use in a factory environment.

## Background

[002] Three dimensional (3D) printers are in rapidly increasing use. One class of 3D printers includes stereolithography printers having a general principle of operation including the selective curing and hardening of radiation curable (photocurable) liquid resins. A typical stereolithography system includes a resin vessel holding the photocurable resin, a movement mechanism coupled to a support surface, and a controllable light engine. The stereolithography system forms a three dimensional (3D) article of manufacture by selectively curing layers of the photocurable resin. Each selectively cured layer is formed at a "build plane" within the resin.

[003] One challenge with stereolithography systems is the cost and variability of human labor. Historically this has been tolerable when these systems have been used for prototyping. As they are used for manufacturing, there is a need to provide designs that enable automation and eliminate variability.

## Brief Description of the Figures

[004] FIG. 1A is an isometric drawing depicting an exemplary three dimensional printing system.

[005] FIG. 1B is a side view of an exemplary three dimensional printing system.

[006] FIG. 1C is a rear view of an exemplary three dimensional printing system.

[007] FIG. 2A is a schematic block diagram of an exemplary three dimensional printing system.

[008] FIG. 2B is an illustration depicting a “build plane” which represents a thin slab of resin being selectively cured by a light engine.

[009] FIG. 3A is a top view of an exemplary resin vessel.

[0010] FIG. 3B is a side view of an exemplary resin vessel.

[0011] FIG. 3C is an isometric view of a lower side of an exemplary resin vessel.

[0012] FIG. 3D is a bottom view of an exemplary resin vessel.

[0013] FIG. 4 is a top view of an exemplary support plate.

[0014] FIG. 5A is a top view of an exemplary support fixture.

[0015] FIG. 5B is a side view of an exemplary support fixture.

[0016] FIG. 5C is a diagram illustrating an “inflow distance” of resin flowing through openings in the support fixture.

[0017] FIG. 6 is a flowchart depicting an exemplary method of manufacturing a three dimensional article of manufacture.

[0018] FIG. 7A is an isometric drawing depicting loading a resin vessel onto a support plate with an interface mechanism in a non-operating state.

[0019] FIG. 7B is an isometric drawing depicting loading a resin vessel onto a support plate with an interface mechanism in an operating state.

[0020] FIG. 7C is an isometric drawing depicting a fluid spill containment vessel about to be loaded onto a lower side of a support plate.

[0021] FIG. 7D is an isometric drawing depicting a fluid spill containment vessel loaded onto a lower side of a support plate.

[0022] FIG. 8A is a simplified cross sectional schematic illustration of tensioning of a transparent sheet.

[0023] FIG. 8B is a simplified diagram of force exerted on the transparent sheet of FIG. 8A.

[0024] FIG. 8C is a simplified cross sectional schematic illustration of an alternative method of tensioning a transparent sheet.

[0025] FIG. 9 is an isometric drawing depicting loading a support fixture onto a receiving arm.

[0026] FIG. 10 is a top view of a portion of an exemplary three dimensional printing system with a resin vessel and support fixture installed.

## Summary

[0027] In a first aspect of the disclosure, a three dimensional printing system includes a vertical support, a support plate, a resin vessel, a carriage, and a support fixture. The support plate has a proximal end affixed to the vertical support and extends along a first lateral axis to a distal end. The resin vessel is supported by the support plate and has a rear side proximate to the proximal end of the support plate. The resin fluid outlet is supported over the rear side of the resin vessel. The carriage is configured to be translated vertically along the vertical support. A pair of fixture receiving arms extend from the carriage along the first lateral axis from a proximal to a distal end. The fixture receiving arms are spaced apart along a second lateral axis that is perpendicular to the first lateral axis. The support fixture is supported by and extends between the two fixture receiving arms.

[0028] In one implementation the three dimensional printing system includes a resin handling module. The resin handling module includes a first module arm supporting the resin fluid outlet and a second module arm supporting a fluid level sensor. The first module arm and the second module arm are spaced apart along the second lateral axis. The first module arm and the second module arm are positioned inside the fixture receiving arms with respect to the second lateral axis.

[0029] In another implementation the resin vessel includes a vessel body having an inner edge defining a central opening and a transparent sheet that closes the central opening to define a lower bound for a body of resin to be contained in the resin vessel.

[0030] In yet another implementation the three dimensional printing system includes a fluid spill containment vessel mounted to a lower side of the support plate. The fluid spill containment vessel includes a pair of upper lips that extend along the first later axis. The support plate includes a pair of rails mounted to the lower side that are configured to slidingly receive the upper lips when the fluid spill containment vessel is slidingly mounted to the lower side of the support plate.

## Detailed Description of the Preferred Embodiments

[0031] FIGS. 1A-C are views of an exemplary three dimensional (3D) printing system 2. FIG. 1A is an isometric view, FIG. 1B is a side view, and FIG. 1C is a rear view. In describing printing system 2 axes X, Y, and Z are used to illustrate positions, directions, and motions. Axes X, Y, and Z are mutually orthogonal. Axes X and Y are "lateral" or "horizontal" axes. Axis Z is a "vertical" axis. Axis Z is typically aligned or nearly aligned with a gravitational reference. In describing directions the following conventions will be used: +Y is to the "right" and –Y is to the "left." +Z is generally upward and –Z is generally downward.

[0032] Three dimensional printing system 2 includes a vertical support 4 having a front side 6 and a back side 8. Vertical support 4 generally provides a "vertical backbone" from which other components of three dimensional printing system 2 are mounted.

[0033] A support plate 10 is mounted to the vertical support 4. Support plate 10 has a proximal end 12 that is proximate to the front side 6 of vertical support 4. Support plate 10 extends from proximal end 12 to distal end 14 along the lateral axis X. Support plate 10 has an inner surface 16 facing inwardly and defining a central opening 18.

[0034] A resin vessel 20 is supported by the support plate 10. The resin vessel 20 has a rear portion 22 that is proximate to the proximal end 12 of the support plate 10. The resin vessel 20 has a front portion 24 that is proximate to the distal end 14 of the support plate 10. Resin vessel 20 has an inner edge 26 that surrounds a central opening 28. The central openings 18 and 28 are laterally aligned with respect to each other to enable an optical path for vertically projected pixelated light. Central opening 28 is laterally contained within central opening 18.

[0035] A resin fluid outlet 30 is positioned over the rear portion 22 of resin vessel 20. A fluid level sensor 32 is positioned over the rear portion 22 of the resin vessel 20. The resin fluid outlet 30 and fluid level sensor 32 are separated from each other along the lateral axis Y.

[0036] A fluid spill containment vessel 34 is releasably mounted to a lower side 36 of the support plate 10. Fluid spill containment vessel 34 is for capturing any resin spills resulting from damage to or overfilling of the resin vessel 20. The fluid spill containment vessel 34 includes a window (to be discussed below). The window is laterally aligned with the central openings 18 and 28 to enable the aforementioned optical path for vertically projected pixelated light.

[0037] Mounted to the rear side 8 of vertical support 4 is a vertical track 38. A carriage 40 is mounted in sliding engagement with the vertical track 38. A motorized lead screw 42 is configured to drive the carriage 40 along vertical axis Z. The lead screw 42 is coupled to motor system 44 which rotates the lead screw 42 to drive the carriage 40 vertically along the vertical track 38. A pair of fixture receiving arms 46 extend from the carriage 40 along the lateral axis X. Supported between the receiving arms 46 is a support fixture 48.

[0038] A light engine 50 is mounted to the vertical support 4 via a support bracket 52. Support bracket 52 extends away from the front side 6 of vertical support 4 along lateral axis X. Pixelated light from light engine 50 is projected vertically upwardly. The pixelated light passes through the fluid spill containment vessel 34, the support plate 10, and the vessel 20 to a build plane within the resin vessel 20.

[0039] FIG. 2A is a block diagram schematic of the three dimensional printing system 2 including some mechanical features and a simplified electrical block diagram. The resin vessel 20 is shown containing resin 54. Resin vessel 20 includes a transparent sheet 55 which defines a lower bound for the resin 54 in vessel 20. The resin is being supplied from resin supply 56 and along a resin supply path 58 to the resin fluid outlet 30. An interface mechanism 60 is configured to controllably latch the resin vessel 20 to the support plate 10 and to position the resin fluid outlet 30 and the fluid level sensor 32 over the resin vessel 20.

[0040] The light engine 50 includes a light source 62 and a spatial light modulator 64. The light engine 50 projects pixelated light 66 up to a "build plane" 68 which is coincident with or proximate to a lower face 70 of a three dimensional article of manufacture 72 being fabricated. Build plane 68 is depicted in FIG. 2B as a two dimensional array of pixels 74. Each pixel 74 corresponds to a pixel element of the spatial light modulator 64.

[0041] Build plane 68 defines a lateral addressable extent of the light engine 50 within the resin vessel 20. The build plane 68 is actually a very thin slab or "slice" of resin with lateral dimensions in X and Y and a small vertical thickness. This slab of resin is selectively cured based upon a "slice" of data that is processed and sent to the spatial light modulator 64. The build plane 68 slab does not touch the transparent sheet 55 because an oxygen, chemical, or other inhibitor is utilized to block polymerization on an upper surface of transparent sheet 55. Each time a portion of the build plane 68 slab is selectively cured, it provides another accretive layer onto the lower face 70 of the three dimensional article of manufacture 72.

[0042] The thickness of resin between the lower face 70 and the transparent sheet 55 is important because it provides an optical path for the pixelated light 66. The weight of the resin 54 and other factors can cause the transparent sheet 55 to bulge between a center 76 and edges 78 of build plane 68. Such a bulge will result in variable curing and dimensional variations as a function of a distance from the center 76. To reduce this factor, a unique tensioning mechanism is provided to maintain flatness of the transparent sheet 55.

[0043] A controller 80 is controllably coupled to fluid level detector 32, motor system 44, light engine 50, resin supply 56, and interface mechanism 60. Controller 80 includes a processor (not shown) coupled to an information storage device (not shown). The information storage device includes a non-transient or non-volatile storage device that stores software instructions that, when executed by the controller 80, operate (and/or receive information from) fluid level detector

32, motor system 44, light engine 50, resin supply 56, interface mechanism 60, and other portions of three dimensional printing system 2. The controller 80 can be located on one circuit board or distributed among multiple circuit boards throughout the three dimensional printing system 2.

[0044] FIGS. 3A-D depict views of the resin vessel 20. FIG. 3A is a top view, FIG. 3B is a side view, FIG. 3C is an isometric view, and FIG. 3D is a bottom view of resin vessel 20. The construction of resin vessel 20 includes resin vessel body 82, transparent sheet 55, and retainer 84 that clamps the transparent sheet 55 to the resin vessel body 82.

[0045] The resin vessel body 82 has an outer peripheral edge 86 and inner edge 26. Inner edge 26 defines the central opening 28 that is closed on a lower side by the transparent film 55. Resin vessel body 82 includes a sloped surface 88 surrounded by a peripheral wall 90 partly defining the outer peripheral edge 86. Peripheral wall 90 helps to contain the resin 54 contained by the resin vessel 20. The sloped surface 88 allows resin to drain toward the central opening 28.

[0046] Resin vessel body 82 has a pair of opposing latch features 92 that are in opposing locations with respect to the lateral axis Y. Formed into the sloped surface 88 of the vessel body 82 is a channel 96 for receiving resin 54 from the resin fluid outlet 30.

[0047] FIG. 4 is a top view depicting the support plate 10. Support plate 10 includes an upper surface 98 including a recessed surface 100 bounded by an inwardly facing wall 102. When the resin vessel 20 is loaded onto the upper surface 98 of support plate 10, a lower portion of resin vessel 20 is partially received into a recess 101 defined between the inwardly facing wall 102 and a raised ridge 104 that rises above the recessed surface 100. The resin vessel 20 is aligned to the support plate 10 by engagement between the outer peripheral edge 86 and the inwardly facing wall 102.

[0048] Extending above the recessed surface 100 is raised ridge 104. When the resin vessel 20 is loaded onto the support plate 10, the raised ridge 104 engages a lower surface of the transparent sheet 55, thereby laterally tensioning the transparent sheet 55. The engagement between the peripheral edge 86 and the inwardly facing wall 102 aligns the raised ridge 104 relative to the inner edge 26 of central opening 28 of resin vessel 20. Aligned, the raised ridge 104 is disposed at a substantially constant distance from the inner edge 26. Simultaneously the central opening 28 of the resin vessel is aligned relative to the central opening 18 of the support plate 10. In the illustrated embodiment the raised ridge 104 defines at least part of the inwardly facing surface or edge 16 that bounds and defines the central opening 18.

[0049] FIGS. 5A and 5B depict support fixture 48. FIG. 5A is a top view and FIG. 5B is a side view. Support fixture 48 includes an upper portion 108, a lower planar portion 110, and a side wall 112 coupling the upper portion 108 to the lower planar portion 110.

[0050] The upper portion 108 includes portions 108X that extend along the lateral X axis and portions 108Y that extend along the lateral Y axis. The portions 108Y are for supporting the support fixture 48 between the receiving arms 46. Each 108Y portion includes a datum feature 114 for receiving and aligning to pins that extend upwardly from the receiving arms 46. The portions 108Y are also made of a magnetic material that is held down by magnets embedded in receiving arms 46. In an illustrative embodiment the entire support fixture 48 is formed from a magnetic material. When the support fixture 48 is being raised, the receiving arms 46 provide support in an upper direction because the receiving arms 46 press upwardly on the portions 108Y. When the support fixture is lowered whereby lower planar portion 110 is passing into resin 54, the magnetic interaction between the upper portion 108 and the receiving arms 46 provides a downward force that secures the support fixture 48 to the receiving arms 46.

[0051] The lower planar portion 110 has a lower surface 116 upon which the three dimensional article of manufacture 72 is formed. Formed into the lower planar portion 110 is a dense array of small openings 118. A primary purpose of the small openings 118 is to reduce a fluid drag just before and at the start of forming the three dimensional article of manufacture 72. Before forming the three dimensional article of manufacture 72, the lower surface 116 is moved through the resin 54 and very close to the transparent sheet 55. As the lower surface 116 approaches the transparent sheet 55, resin is displaced and must flow laterally from between the lower surface 116 and the transparent sheet 55. Without such openings 118 the force exerted on the transparent sheet 55 can be large enough to bulge or even damage the transparent sheet 55.

[0052] The openings 118 allow the resin 54 to escape vertically through the lower planar portion 110 of the support fixture 48. But there is still a vertical force being exerted upon the transparent sheet 55. This vertical force varies positively with an "inflow distance" D. FIG. 5C illustrates the inflow distance D between three small openings 118. The inflow distance D is a geometric parameter that varies monotonically with a vertical force that is indirectly exerted between the lower surface 116 and the transparent sheet 55 by the thin layer of resin 54 therebetween.

[0053] The inflow distance 120 is geometrically defined as the distance that resin must flow out of an opening 118 between the transparent sheet 55 and the lower surface 116 before the entire lower surface 116 is covered with resin. This occurs when the dashed circles representing a "resin front" flowing out of the circles close all uncovered gaps. This therefore occurs when the resin fronts intersect at a midpoint between the arrangement of the three openings 118.

[0054] Defining some terms: S = the center to center distance between the openings along Y. R = opening radius. D = the inflow distance between an edge of the opening and the midpoint between the openings. Using geometry, the result is that $D = S/\sqrt{3} - R$ for this arrangement of openings.

[0055] For a particular example, the center to center distance S is 4.5 millimeters. The opening radius R is 1.5 millimeters. Then the inflow distance D is about 1.1 millimeters (rounding to the first significant figure).

[0056] Preferably the dense array of small openings 118 cover the entire area of the build plane 68 in order to minimize a vertical force exerted on the transparent sheet 55. In one embodiment the dense array of small openings 118 includes at least 100 small openings 118. In another embodiment the dense array of small openings 118 includes at least 200 small openings 118.

[0057] In some embodiments the inflow distance is less than 3 millimeters. In other embodiments the inflow distance is less than 2 millimeters. In yet other embodiments the inflow distance is less than 1.5 millimeters.

[0058] The small openings 118 are the primary feature in reducing fluid drag and force on the transparent sheet 55 just before and at the beginning of forming the three dimensional article of manufacture 72 (and/or when lower surface 116 is moving vertically through resin proximate to the upper surface of the transparent sheet 55). As the three dimensional article of manufacture 72 is being formed, the distance between the lower surface 116 and the transparent sheet 55 increases and the effect of the openings 118 decreases.

[0059] Formed along the side wall 112 are a plurality of large openings 120. The large openings 120 reduce the fluid drag of the resin 54 as the lower planar portion 110 of the support fixture 48 is being raised or lowered in the resin 54. During fabrication of a three dimensional article of manufacture 72 the large openings 120 become a greater factor than the smaller openings 118 in reducing fluid drag when a sufficient portion of the three dimensional article of manufacture 72 is formed. The large openings 120 also provide the function of allowing residual resin 54 to drain from the support fixture 48 when the lower planar support portion 110 is lifted out of the resin 54 in resin vessel 20.

[0060] The large openings 120 reduce a fluid pressure difference between the resin 54 inside the side wall 112 of the support fixture 48 and outside the side wall 112 as the lower planar portion is being raised and lowered within the resin 54. As the lower planar portion 110 is being lowered into the resin 54, the large openings 120 allow resin to flow into the space above the lower planar portion 112. As the lower planar portion 110 is being raised, the large openings allow the resin to flow out of the space above the lower planar portion 112.

[0061] According to the illustrated embodiment the large openings 120 are distributed to surround the dense array of small openings 118. The large openings are at least partially formed into the side wall 112. In some embodiments, individual large openings 120 span the side wall 112 and an edge of the lower support portion 110. In one embodiment a large opening 120 has a cross sectional area equal to at least a plurality of the cross sectional area of one small opening 118. In another embodiment the large opening 120 has a cross sectional area equal to at least five times the cross sectional area of one small opening 118. In another embodiment the large opening 120 has a cross sectional area equal to at least ten times the cross sectional area of one small opening 118.

[0062] The side wall 112 is preferably angled relative to vertical axis Z to enable a nested stacking of the support fixtures 48. This enables a stack of support fixtures 48 to be loaded into a magazine for automated loading into a printing system 2. In one embodiment the angle of the side wall 112 relative to the vertical axis Z is in a range of 10 to 50 degrees. In another embodiment the angle of the side wall 112 relative to the vertical axis Z is in a range of 20 to 40 degrees. In yet another embodiment the angle of the side wall 112 relative to the vertical axis Z is in a range of 25 to 35 degrees. In a further embodiment the angle of the side wall 112 relative to the vertical axis Z is about 30 degrees. There is a tradeoff in the angle. As the angle increases, a required area of the support fixture 48 and resin vessel 20 increases for a given area of a build plane

68. Thus, a minimal angle may seem optimized. However as the angle decreases, vertical stacking efficiency of the support fixtures 48 decreases. Therefore an angle of about 30 degrees from vertical is roughly an optimal tradeoff for vertical stacking efficiency versus size.

[0063] The portions 108X of the upper portion 108 that extend along the X axis include a plurality of bent tabs 122 that extend above an upper planar surface 124 of the portions 108X. The bent tabs 122 are for engaging a lower planar surface 126 of the portions 108X to provide a controlled vertical spacing between stacked support fixtures 48. In the illustrative embodiment an individual bent tab 122 is bent into a U-shape whereby an end of the tab 122 faces inwardly.

[0064] FIG. 6 is a flowchart representing a manufacturing method 130 for using printing system 2 to fabricate a three dimensional article of manufacture 72. Some individual steps of method 130 will also be described and/or illustrated with respect to subsequent figures in added detail. Also, some of the earlier figures pertain to method 130. Most or all of the steps of method 130 can be under control of the controller 80. For steps 132, 136, and 146 any or all of these can be performed either manually or with a robotic arm under control of the controller 80. Remaining steps 134, 138-144, and 148 can be controlled by the controller 80.

[0065] According to step 132, the resin vessel 20 is loaded onto support plate 10. According to step 134, the interface mechanism 60 is activated to secure the resin vessel 20 to the support plate 10 and to position the resin fluid outlet 30 and the fluid level sensor 32 over the resin vessel 20. According to step 136, the support fixture 48 is loaded onto the fixture receiving arms 46. In some embodiments step 136 is performed before step 134 and/or before step 132.

[0066] According to step 138, the resin supply 56 is activated whereby the resin supply 56 supplies resin to the resin vessel 20. According to this step the controller 80 utilizes the fluid level sensor 32 to monitor a fluid level of the resin

54 in the resin vessel 20. The controller 80 activates the resin supply 56 to pump resin 54 through the supply path 58 and out the resin fluid outlet 30 until a proper level of resin 54 is present in resin vessel 20. During subsequent steps, the controller 80 can continue to monitor information from the fluid level sensor 32 and operate the resin supply 56 to maintain a proper level of resin in the resin vessel 20.

[0067] According to step 140, the motor system 44 operates the lead screw 42 to translate the carriage 40 whereby the lower surface 116 of support fixture 46 is positioned at an operating distance from the transparent sheet 55. According to step 142, the light engine 50 is activated to selectively polymerize a layer of the resin onto the lower surface 116. Steps 140 and 142 are repeated until the entire three dimensional article of manufacture 72 is formed. As a note, when step 140 is repeated, it is the lower face 70 of the three dimensional article of manufacture 72 that is positioned at the operating distance from the transparent sheet 55.

[0068] According to step 144, the motor system 44 is operated to raise the three dimensional article of manufacture 72 out of the resin 54. According to step 146 the support fixture 48 is unloaded from the receiving arms 46. According to step 148, the interface mechanism 60 is operated to move the resin fluid outlet 30 and the fluid level sensor 32 from above the resin vessel 20. Also according to step 148 the resin vessel 20 is unlatched so that it can be removed from the support plate 10.

[0069] As a note various alternative embodiments are possible. For example, step 148 can be skipped and the process can proceed to step 136 whereby another support fixture 48 is loaded for forming another three dimensional article of manufacture 72 with the same resin vessel 20. Thus, the depicted method 130 is illustrative and lends itself to certain variations.

[0070] FIGS. 7A-D are isometric views depicting loading and securing the resin vessel 20 and the fluid spill containment vessel 34 to the support plate 10. FIG.

7A depicts step 132 of FIG. 6. The resin vessel 20 has been loaded onto the support plate 10. A lower portion of resin vessel 20 has been received into the recess 101 (see also FIG. 4). Engagement of the peripheral edge 86 and the inwardly facing wall 102 has provided lateral (X and Y) alignment of the resin vessel 20 with respect to the support plate 10.

[0071] Also shown in FIG. 7A is a resin handling module 150 that supports both the resin fluid outlet 30 and the fluid level sensor 32 with arms 154. The resin handling module 150 is configured to rotate about an axis parallel to lateral axis Y. In FIG. 7A the resin handling module 150 is shown in a non-operating position whereby the resin fluid outlet 30 and the fluid level sensor 32 are not in position over the resin vessel 20. Latches 152 are also shown in a non-engaged position.

[0072] FIG. 7B depicts step 134 of FIG. 6. Between FIGS. 7A and 7B the resin handling module 150 has been rotated about an axis parallel to lateral axis Y from a non-operating position (FIG. 7A) to an operating position (FIG. 7B). In the operating position the resin fluid outlet 30 and the fluid level sensor 32 are both positioned over the resin vessel 20. Also the latches 152 are engaged with latch features 92 at opposing ends of the resin vessel. The latches 152 exert a downward (-Z) vertical force on the latch features 92 to increase a tension in the transparent sheet 55.

[0073] The resin handing module 150 includes two arms 154 that are linked together whereby they rotate together in unison between the non-operating position and the operating position of the resin handling module 150. The interface mechanism 60 that actuates the resin handling module 150 and the latches 152 is configured to simultaneously actuate them to move them back and forth between a non-operating state (non-operating position of resin handling module 150 and latches 152 not engaged) to an operating state (operating position of resin handling module 150 and latches 152 engaged).

[0074] In the illustrative embodiment, the interface mechanism 60 includes pneumatic actuators 156. FIG. 7C depicts a more complete view of the pneumatic actuators 156 (shown without air "plumbing"). There is a pneumatic actuator 156 coupled to each latch 152 and a pneumatic actuator 156 coupled to the resin handling module 150. The air pressure applied to the pneumatic actuators 156 enables motion of the resin handling module 150 and latches 152 to be simultaneous.

[0075] The resin vessel 20 is unloaded in reverse order of being loaded. This includes (1) changing the interface mechanism 60 from an operating to a non-operating state – going from FIG. 7B to FIG. 7A, and then (2) unloading the resin vessel 20 from the support plate 10.

[0076] FIGS. 7C and 7D depict the fluid spill containment vessel 34 being slidingly mounted to the lower side 36 of the support plate 10. The fluid spill containment vessel 34 includes a transparent window 158 for allowing light to pass from the light engine 50 to the resin vessel 20. The fluid spill containment vessel 34 has a generally tapering profile from a distal end 160 to a proximal end 162. The tapering profile provides an internal slope whereby resin can drain away from the transparent window 158 and into a trough 164. This minimizes a tendency for a light path from the light engine 50 to the build plane 68 to be occluded by spilled resin that has accumulated in the fluid spill containment vessel 34.

[0077] The fluid spill containment vessel 34 has a pair of opposing upper lips 166 that extend outwardly along the lateral Y axis. Mounted to the lower side 36 of support plate 10 are two rails 168 that are aligned with lateral axis X and spaced apart with respect to lateral axis Y. The fluid spill containment vessel 34 is mounted to the support plate 10 by slidingly engaging the rails 168 with the upper lips 166 along the lateral axis Y.

[0078] FIGS. 7C and 7D depict disengaged and engaged positions respectively of the fluid spill containment vessel 34 with respect to the support plate 10. In the engaged state, the resin vessel central opening 28, the support plate central opening 18, and the fluid spill containment vessel 34 transparent window 158 are all aligned whereby the light engine 50 can project pixelated light up through them and to the build plane 68.

[0079] FIG. 8A is cross sectional view depicting interaction of components involved in tensioning the transparent sheet 55 during steps 132 and 134 of FIG. 6. When the resin vessel 20 is loaded onto the support plate 10, the raised ridge 104 engages the transparent sheet 55. When the latches 152 engage the latch features 92, they exert a combined downward latch force $F_L$ upon the resin vessel. This has the effect of tensioning the transparent sheet 55. The tension in the transparent sheet 55 can be controlled by controlling the latch force $F_L$.

[0080] FIG. 8B depicts the forces involved: T = Tension in Transparent Sheet 55, $F_H$ = Horizontal Force Exerted on Transparent Sheet by Vessel Body 82, f = horizontal frictional force exerted on transparent sheet 55 by raised ridge 104, $F_V$ = vertical force exerted on transparent sheet 55 by Vessel Body 82, and $F_R$ = Vertical Force Exerted by Raised Ridge 104 on Transparent Sheet 55. Now, $F_V = W_V + F_L$, where $W_V$ is the weight of the resin vessel 20 and $F_L$ is the downward force of both latches. These forces are known.

[0081] Summing the forces in X: $T + f = F_H$. Summing the forces in Y: $F_V = F_R$. From geometry the tangent of θ equals $F_V$ divided by $F_H$. From the above relationships, and from computing the frictional force f based a coefficient of friction and $F_R$, the tension T can be approximated in terms of known variables. This diagram is a simplified approximation of the actual system because it is in two dimensions and the actual system would consider the sheet in three dimensions. If the angle θ is small, then the tension T can be quite large relative to the vertical forces applied. There may be a need to increase the vertical force over time to compensate for an increase in angle θ if the transparent sheet 55 stretches. The configuration of FIG. 8A has an advantage that the latch force $F_L$ can be programmably controlled by the controller 80 controlling the air pressure applied to pneumatic actuators 156. Thus, the tension T can be indirectly programmably controlled by the controller 80.

[0082] FIG. 8C illustrates an alternative embodiment in which the resin vessel 20 “bottoms out” on the support plate 10. With this embodiment, the tension T in the transparent sheet 55 is governed by a vertical position of the vessel body 82 in relation to the raised ridge 104. In this embodiment, any compression set in the transparent sheet 55 will reduce the tension T. While this embodiment is viable, it would be less desirable than the embodiment of FIG. 8A if the transparent sheet 55 stretches over time and/or if dimensional tolerances are not precisely controlled.

[0083] FIG. 9 depicts a mechanical interaction between the portion 108Y of the support fixture 48 and receiving arm 46 as the support fixture is loaded according to step 136 of FIG. 6. The receiving arm 46 includes upstanding pin 170 that is received by datum feature 114 for providing lateral alignment of the support fixture 48. Between both support arms the lateral alignment provided includes X, Y, and rotation about the axis Z. The portion 108Y is formed from a magnetic material and receiving arm contains a magnet. The magnetic interaction and mechanical interaction along the vertical axis Z between portions 108Y and the receiving arms provide support along the vertical axis Z and against rotation about the horizontal axes.

[0084] FIG. 10 is a top view of an embodiment of three dimensional printing system 2 with the resin vessel 20 and the support fixture 48 installed. The vertical support 4 has a front side 6 and a back side 8. Extending from the front side 6 is the support plate 10. The support plate 10 extends along lateral axis X from a proximal end 12 (proximate to the front side 6) to a distal end 14.

[0085] Resin vessel 20 is disposed above a portion of the upper surface 98 of support plate 10 (held above a recessed portion 100 of the upper surface by the force of the raised ridge 104 upon the transparent sheet 55). The resin vessel 20 has a rear portion 22 that is laterally proximate to the proximal end 12 of the support plate. The resin vessel 20 has a front portion 24 that is laterally proximate to the distal end 14 of the support plate. The resin vessel 20 has a pair of opposed latch features 92 including left and right latch features 92 at opposed ends with respect to the lateral axis Y. Corresponding to the left and right latch features 92 are left and right latches 152.

[0086] The interface mechanism 60 (depicted in block diagram form in FIG. 2A) is activated whereby the resin handling module 150 and latches 152 are in an operating state. In the operating state the resin handling module 150 is in an operating position whereby the resin fluid outlet 30 and the fluid level sensor 32 are positioned over the resin vessel 20 and the latches 152 are engaged with the latch features 92 of resin vessel 20. The resin fluid outlet 30 and the fluid level sensor 32 are disposed over the rear portion 22 of the resin vessel 20. The resin fluid outlet 30 and the fluid level sensor 32 are also spaced apart and on either side of the vertical support 4 with respect to the lateral axis Y and each are supported by an arm 154 of the resin handing module 150.

[0087] Extending from the back side 8 of vertical support 4 is carriage 40. Extending forwardly (+X) along lateral axis X from carriage 40 are the receiving arms 46. The receiving arms 46 are spaced apart along the lateral axis Y to an extent that the arms 154 are between the receiving arms 46. Installed between receiving arms 46 is the support fixture 48 that spans a space between the receiving arms 46 along the lateral axis Y.

[0088] The specific embodiments and applications thereof described above are for illustrative purposes only and do not preclude modifications and variations encompassed by the scope of the following claims.

WHAT IS CLAIMED:

1. A three dimensional printing system for fabricating a three dimensional article of manufacture comprising:

a vertical support;

a support plate affixed to the vertical support and extending therefrom along a first lateral axis from a proximal end to a distal end;

a resin vessel supported by the support plate, the resin vessel having a rear side proximate to the proximal end of the support plate;

a resin fluid outlet that is supported over the rear side of the resin vessel;

a carriage configured to be translated vertically along the vertical support;

a pair of fixture receiving arms that extend from the carriage along the first lateral axis from a proximal to a distal end, the fixture receiving arms spaced apart along a second lateral axis that is perpendicular to the first lateral axis; and

a support fixture supported by and extending between the two fixture receiving arms.

2. The three dimensional printing system of claim 1 wherein the resin fluid outlet is supported by a resin handling module having a first module arm supporting and positioning the fluid outlet over the rear side of the resin vessel.

3. The three dimensional printing system of claim 2 further comprising a fluid level sensor and wherein the resin handling module includes a second module arm supporting the fluid level sensor over the rear side of the resin vessel and wherein the first module arm and the second module arm are spaced apart along the second lateral axis.

4. The three dimensional printing system of claim 3 wherein the resin module arms are positioned between the fixture receiving arms with respect to the second lateral axis.

5. The three dimensional printing system of claim 1 wherein the resin vessel includes:

a vessel body having an inner edge defining a central opening; and

a transparent sheet that closes the central opening to define a lower bound for a body of resin to be contained in the resin vessel.

6. The three dimensional printing system of claim 5 wherein the vessel body has an upper surface defining a channel having a receiving end proximate to the rear side of the resin vessel and extending along the first lateral axis to allow fluid flow to the central opening, the fluid outlet is positioned over the receiving end of the channel.

7. The three dimensional printing system of claim 5 wherein the vessel body has two lateral sides each extending along the first lateral axis each having a latch feature and further comprising two latches that are configured to engage the latch features to secure the resin vessel to the support plate.

8. The three dimensional printing system of claim 5 wherein the support fixture includes:

a lower planar portion having a lower surface upon which the three dimensional article of manufacture is formed;

a side wall extending upwardly from the lower planar portion; and

a pair of upper portions extending outwardly in two directions from the side wall and supported by the two fixture receiving arms.

9. The three dimensional printing system of claim 8 wherein a pair of pins extended upwardly from the fixture receiving arms, the pair of upper portions define two datum features that receive the pair of pins when the support fixture is loaded onto the fixture receiving arms.

10. The three dimensional printing system of claim 8 wherein the pair of upper portions are formed from a magnetic material, the fixture receiving arms include magnets that hold the upper portions onto the fixture receiving arms.

11. The three dimensional printing system of claim 1 further comprising a fluid spill containment vessel mounted to a lower side of the support plate.

12. The three dimensional printing system of claim 11 wherein the fluid spill containment vessel includes a pair of upper lips that extend along the first lateral axis and further comprising a pair of rails mounted to the lower side of the support plate that are configured to slidingly receive the pair of upper lips when the fluid spill containment vessel is slidingly mounted to the lower side of the support plate.

13. A three dimensional printing system for fabricating a three dimensional article of manufacture comprising:

a vertical support, the vertical support having a front side and a back side;

a motor system mounted to the back side of the vertical support;

a lead screw coupled to the motor system and extending vertically proximate to the back side of the vertical support;

a support plate affixed to the vertical support and extending from the front side along a first lateral axis from a proximal end to a distal end;

a resin vessel supported over the support plate, the resin vessel having a rear side corresponding to and proximate to the proximal end of the support plate;

a resin fluid outlet that is supported over the resin vessel along the rear side of the resin vessel;

a carriage mounted to the backside of the vertical support and engaged by the lead screw so as to be translated vertically along the vertical support;

a pair of fixture receiving arms that extend from the carriage along the first lateral axis from a proximal to a distal end, the support arms spaced apart along a second lateral axis that is perpendicular to the first lateral axis; and

a support fixture supported by and extending between the two fixture receiving arms.

14. The three dimensional printing system of claim 13 further comprising a light engine mounted to the vertical support whereby it projects pixelated light up to the resin vessel.

15. A three dimensional printing system for fabricating a three dimensional article of manufacture comprising:

a vertical support having a front side;

a support plate affixed to the vertical support and extending from the front side along a first lateral axis from a proximal end to a distal end;

a resin vessel supported over the support plate, the resin vessel having a rear side corresponding to and proximate to the proximal end of the support plate;

a resin fluid outlet that is supported over the resin vessel along the rear side of the resin vessel;

a vessel body having an inner edge defining a central opening; and

a transparent sheet that closes the central opening to define a lower bound for a body of resin to be contained in the resin vessel;

a carriage configured to be translated vertically along the vertical support;

a pair of fixture receiving arms that extend from the carriage along the first lateral axis from a proximal to a distal end, the support arms spaced apart along a second lateral axis that is perpendicular to the first lateral axis; and

a support fixture supported by and extending between the two fixture receiving arms;

a support bracket extending from the front side of a lower end of the vertical support; and

a light engine mounted to the support bracket and configured to project pixelated light upwardly through the transparent sheet to define a build plane within the resin.

16. The three dimensional printing system of claim 15 further comprising a fluid spill containment vessel mounted to a lower surface of the support plate.

17. The three dimensional printing system of claim 16 wherein the fluid spill containment vessel includes a window that laterally aligns with the central opening of the vessel body whereby the pixelated light from the light engine projects up through the window and to the transparent sheet.

18. The three dimensional printing system of claim 17 wherein fluid spill containment vessel has distal and proximal ends corresponding to the distal and proximal ends of the support plate, the fluid spill containment vessel generally tapers from the distal end to the proximal end to provide a containment trough to allow resin to drain away from the clear window and into the trough.

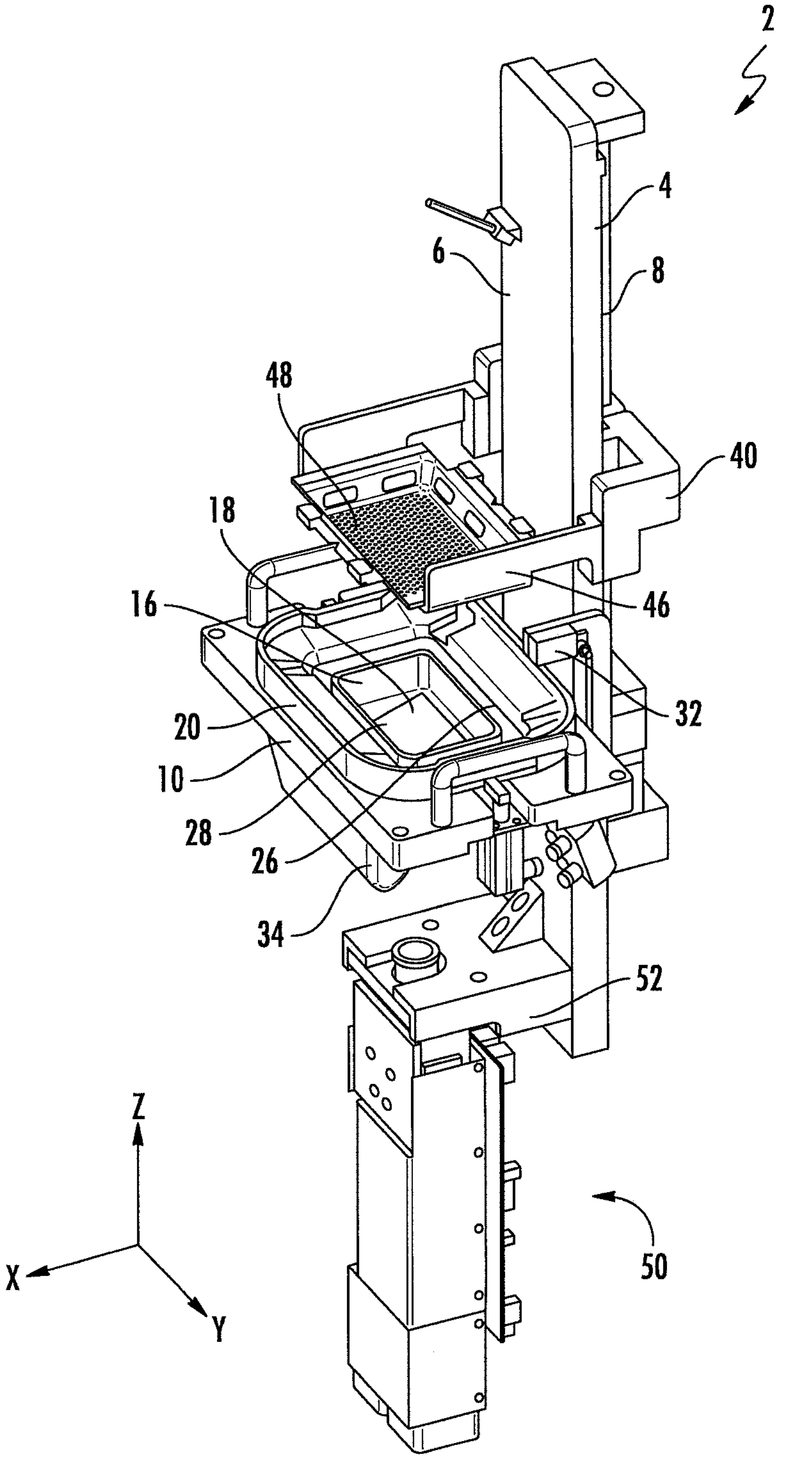


FIG. 1A

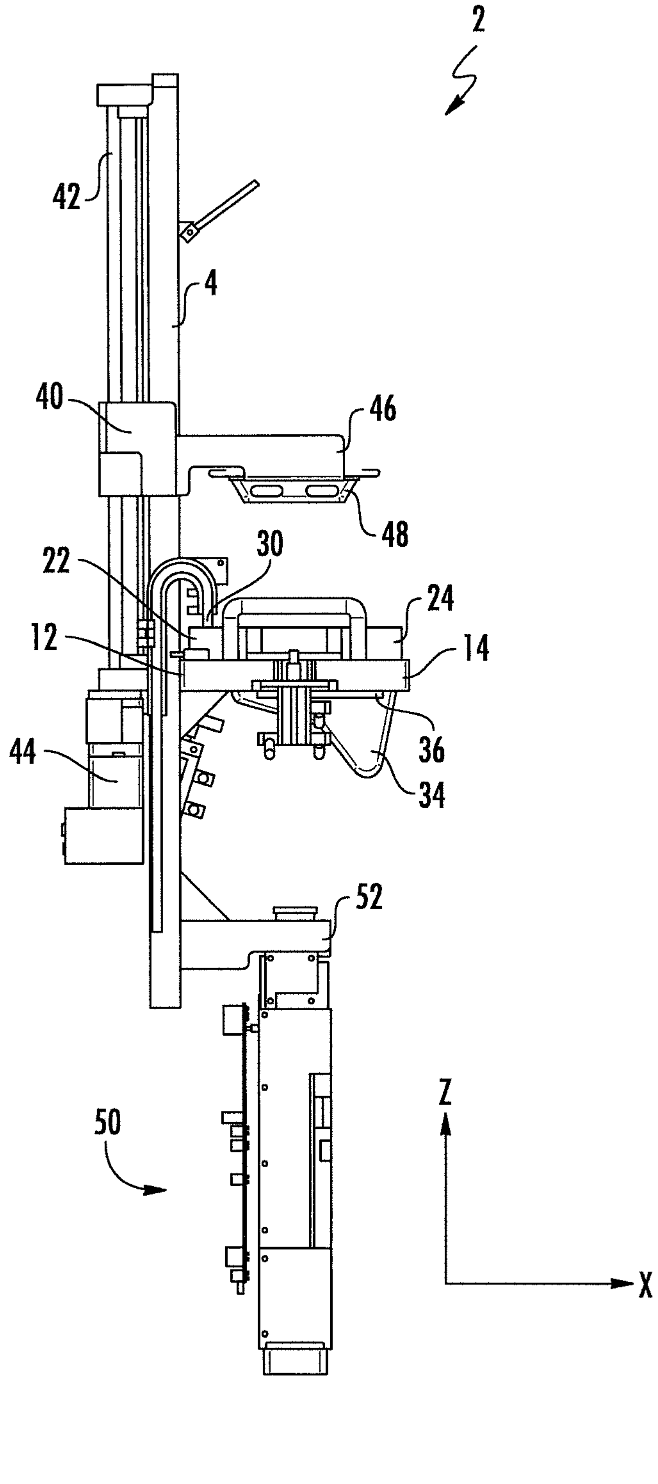


FIG. 1B

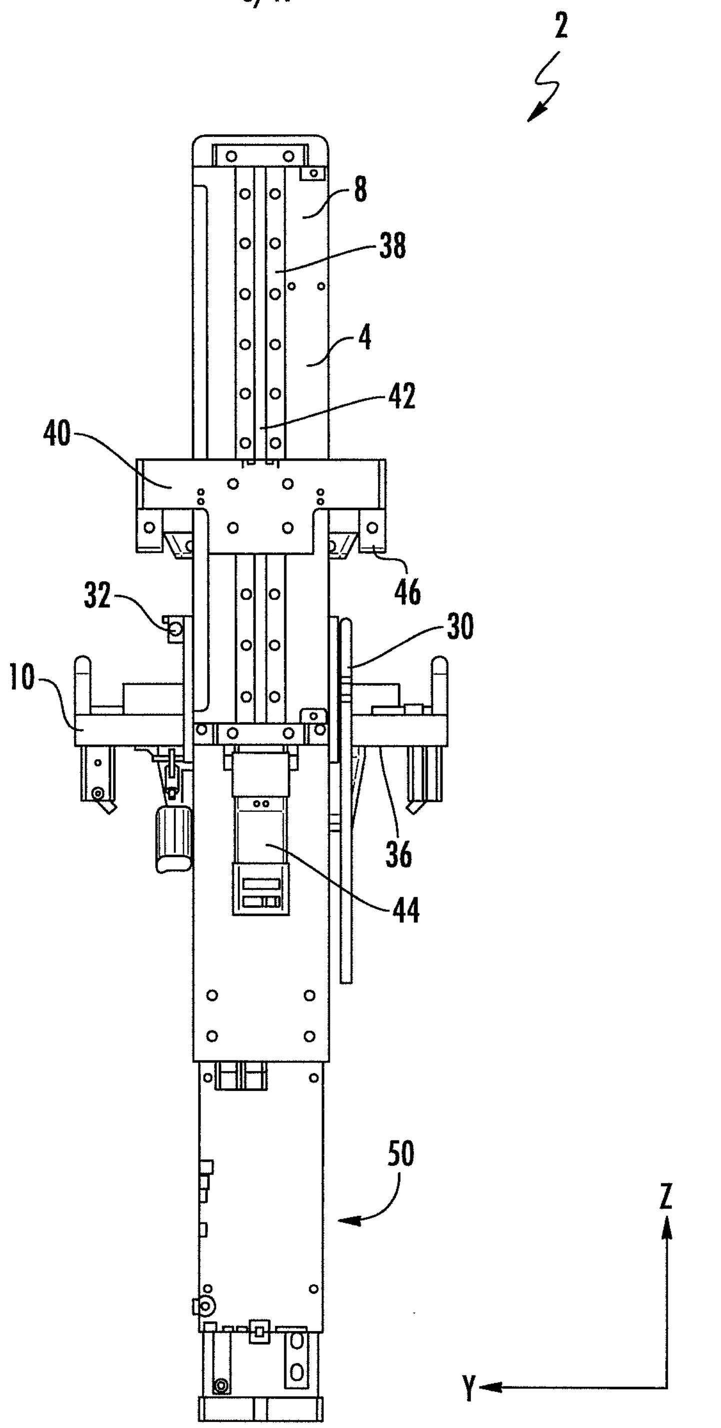


FIG. 1C

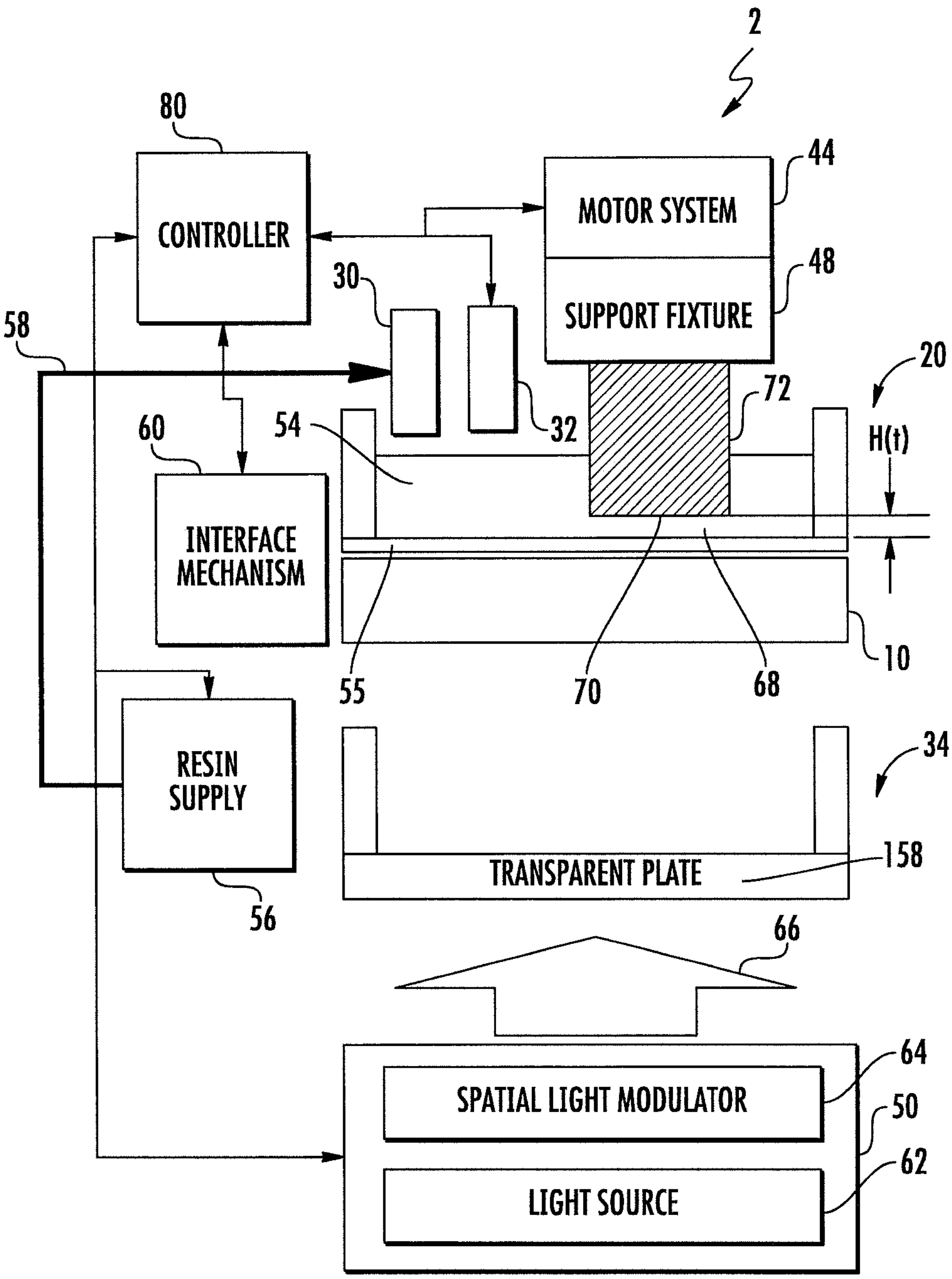
2
80
CONTROLLER
MOTOR SYSTEM
44
SUPPORT FIXTURE
48
30
58
20
72
H(t)
54
32
60
INTERFACE MECHANISM
10
55
70
68
RESIN SUPPLY
34
TRANSPARENT PLATE
158
56
66
SPATIAL LIGHT MODULATOR
64
50
LIGHT SOURCE
62

FIG. 2A

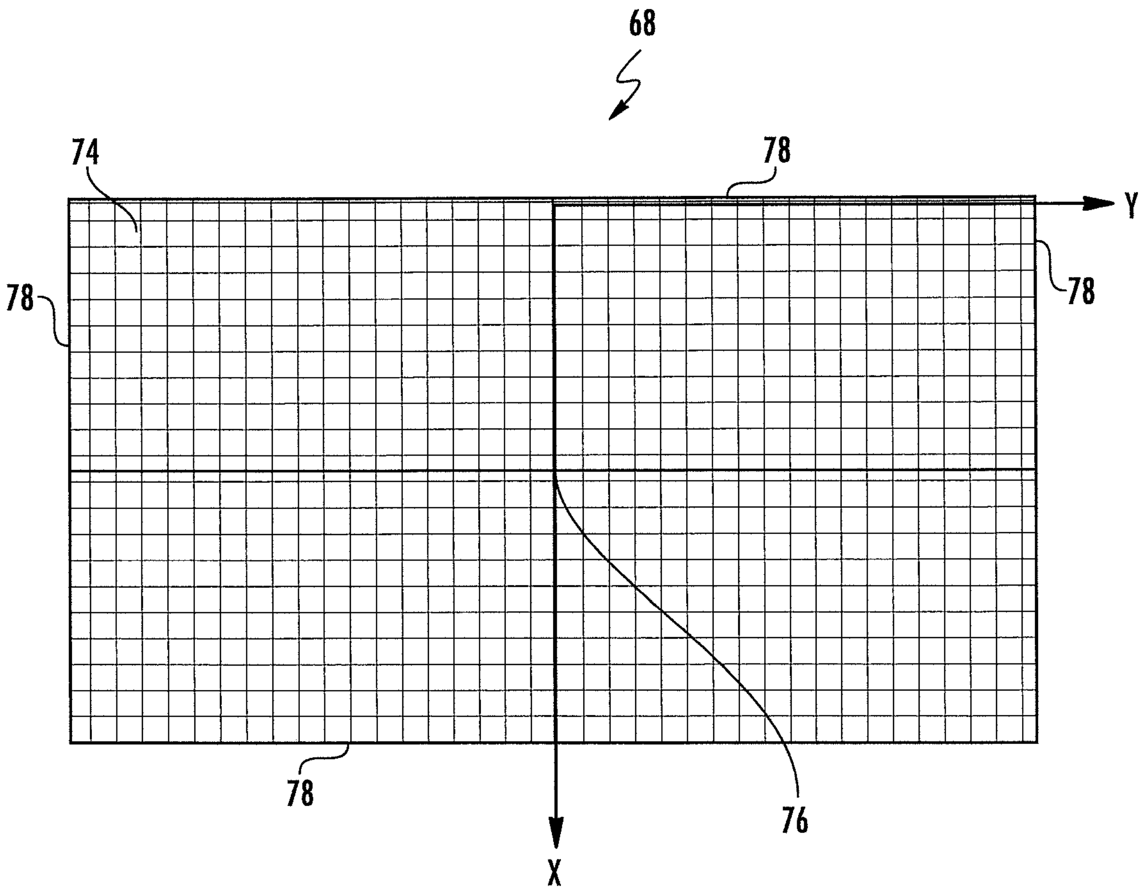


FIG. 2B

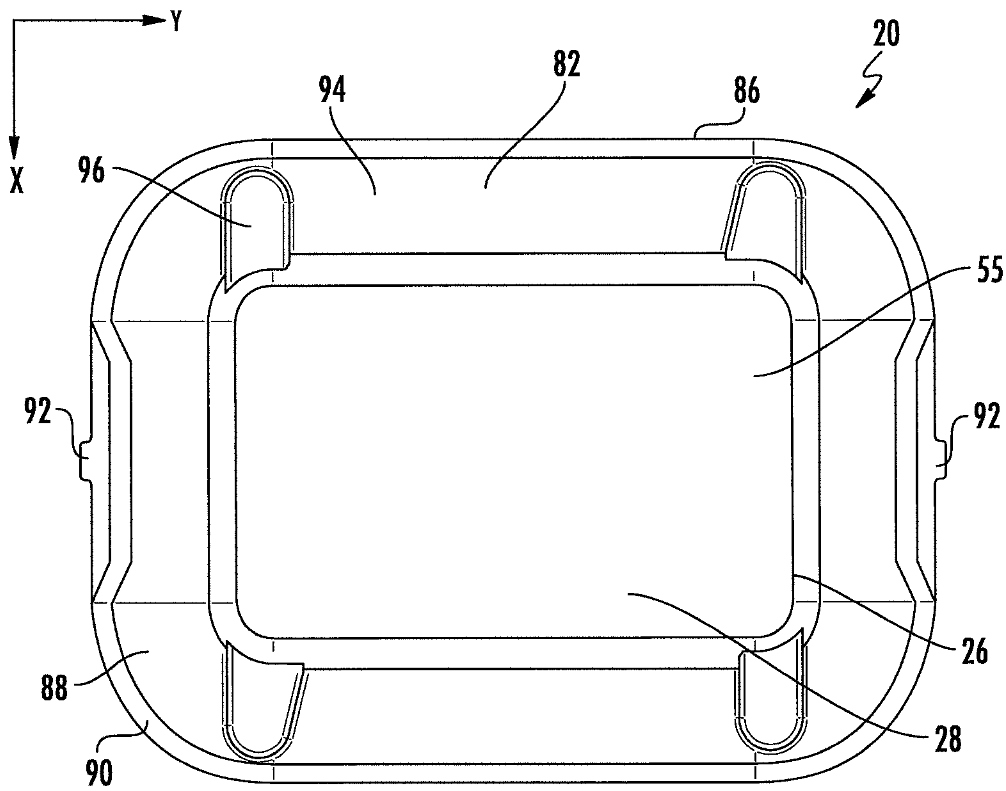


FIG. 3A

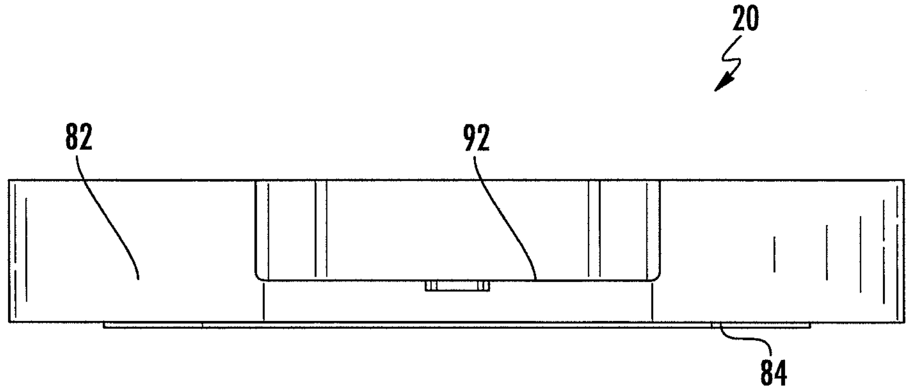


FIG. 3B

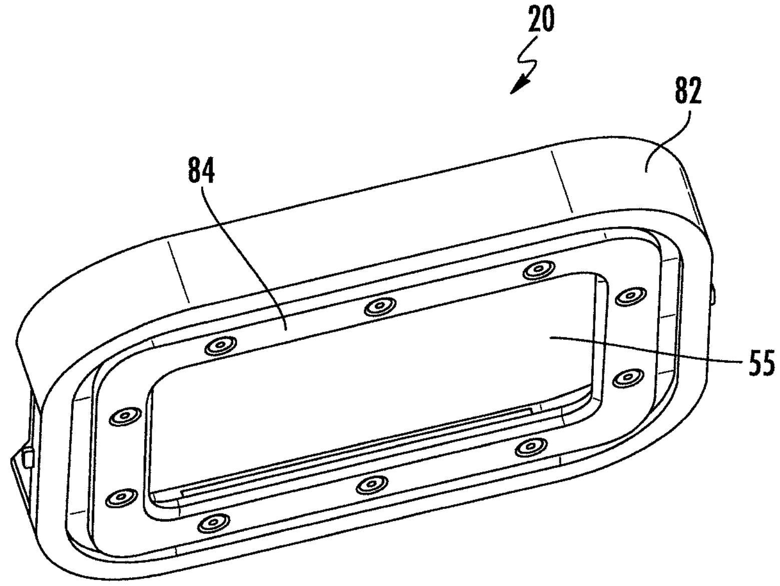


*FIG. 3C*

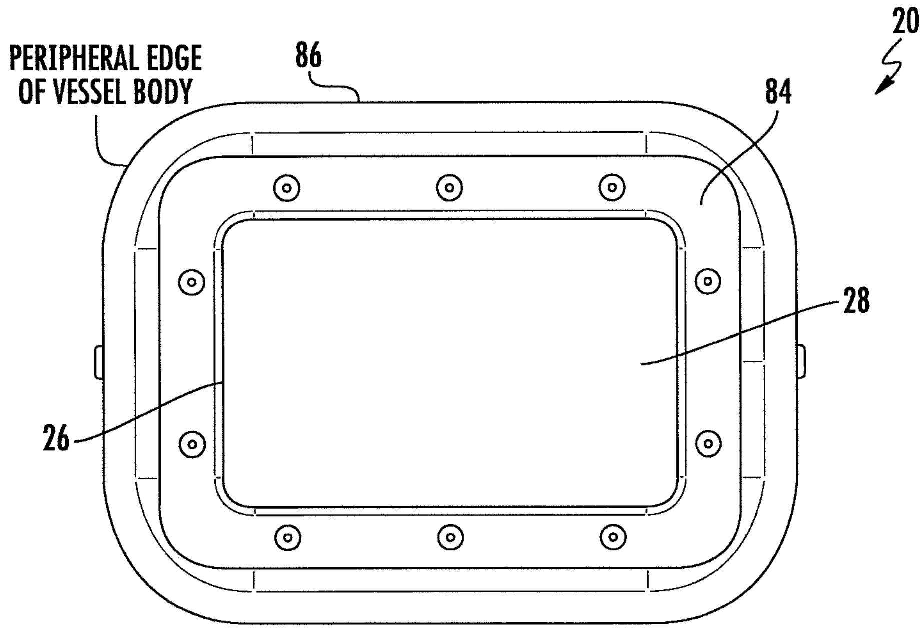


*FIG. 3D*

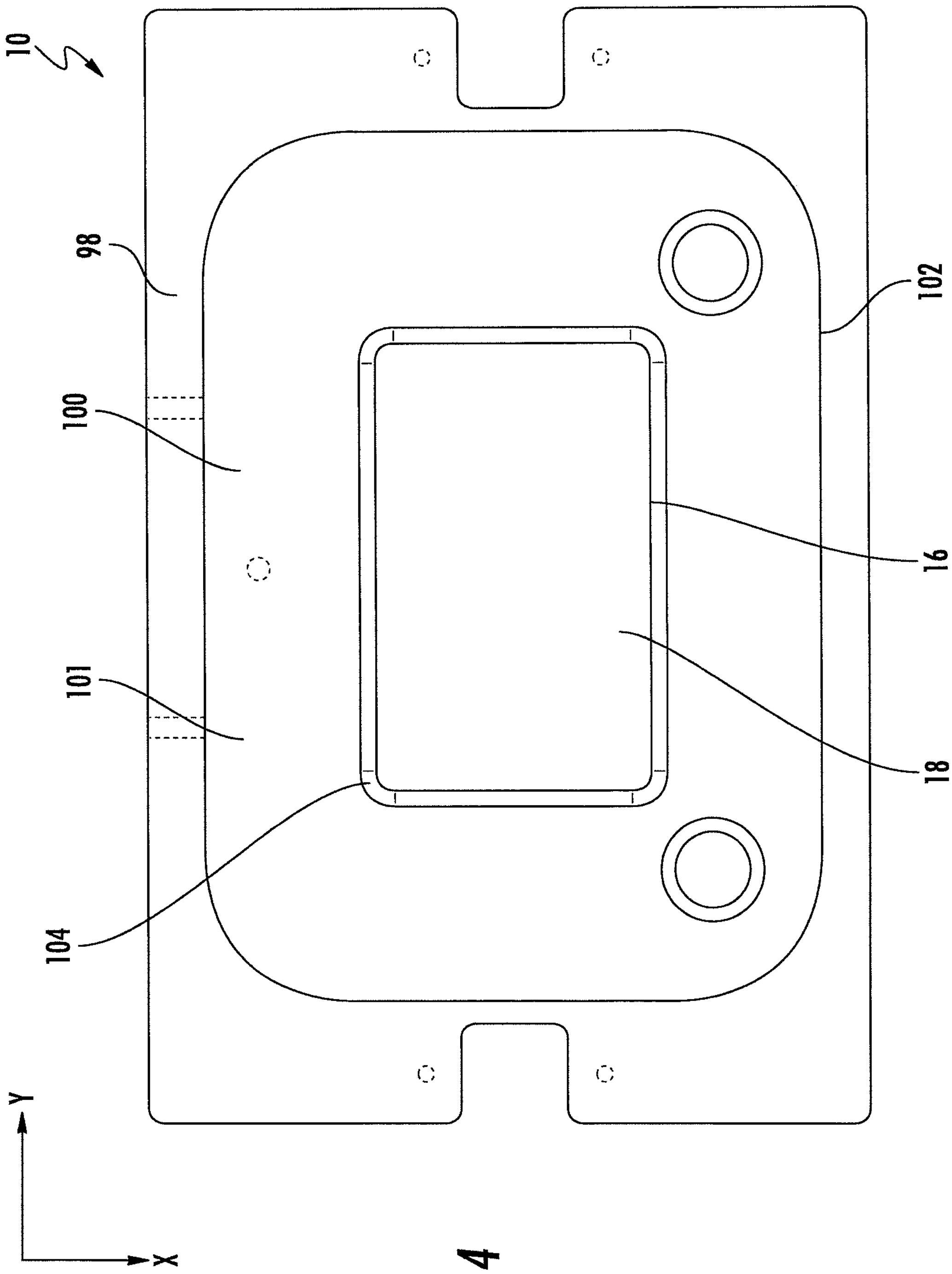


FIG. 4

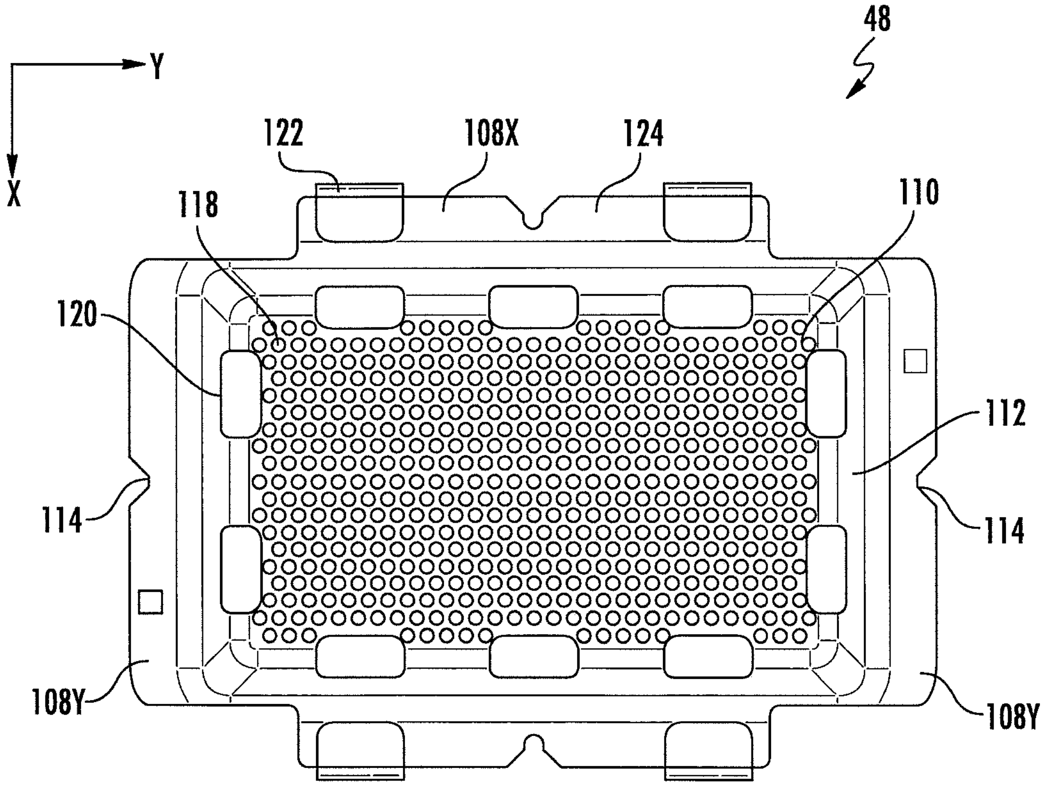
48
Y
X
122
108X
124
118
110
120
112
114
114
108Y
108Y

FIG. 5A

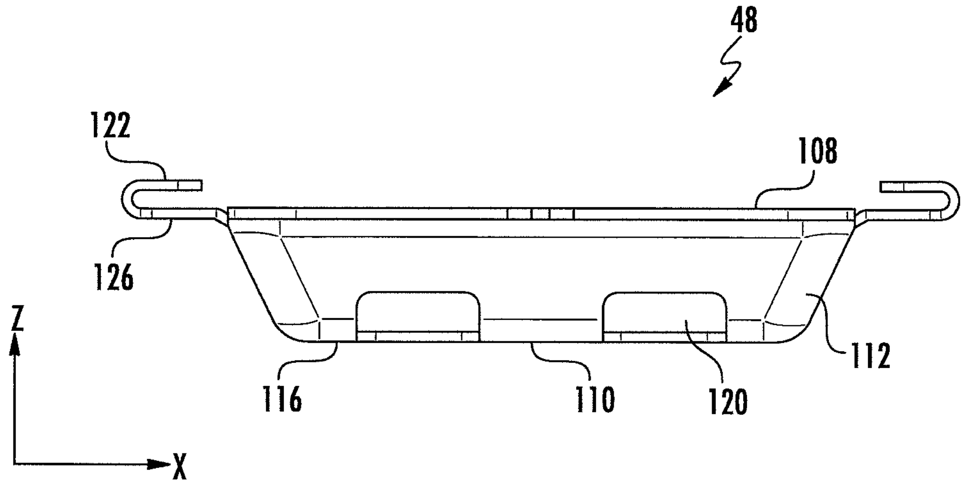
48
122
108
126
Z
116
110
120
112
X

FIG. 5B

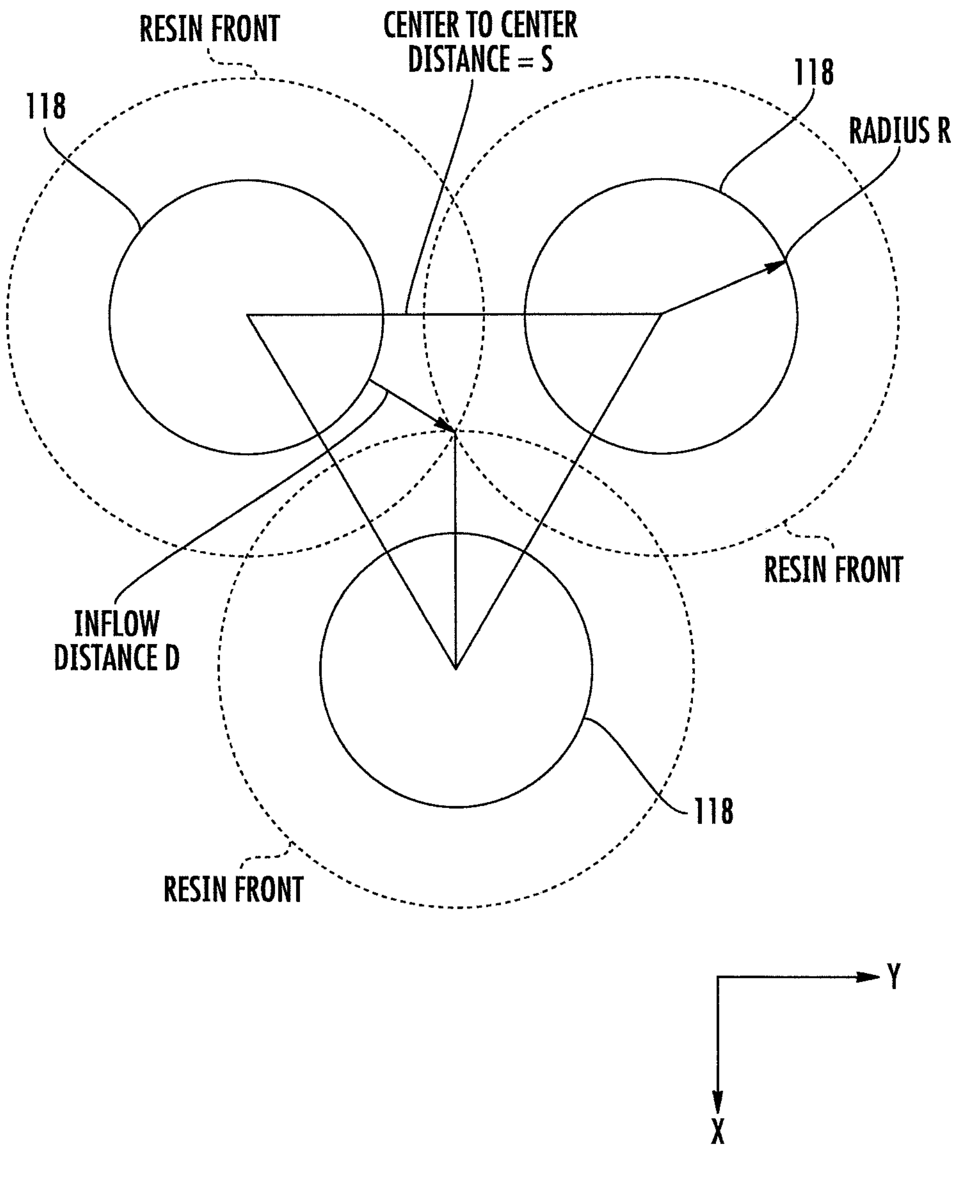
RESIN FRONT
CENTER TO CENTER
DISTANCE = S
118
118
RADIUS R
RESIN FRONT
INFLOW
DISTANCE D
118
RESIN FRONT
Y
X

FIG. 5C

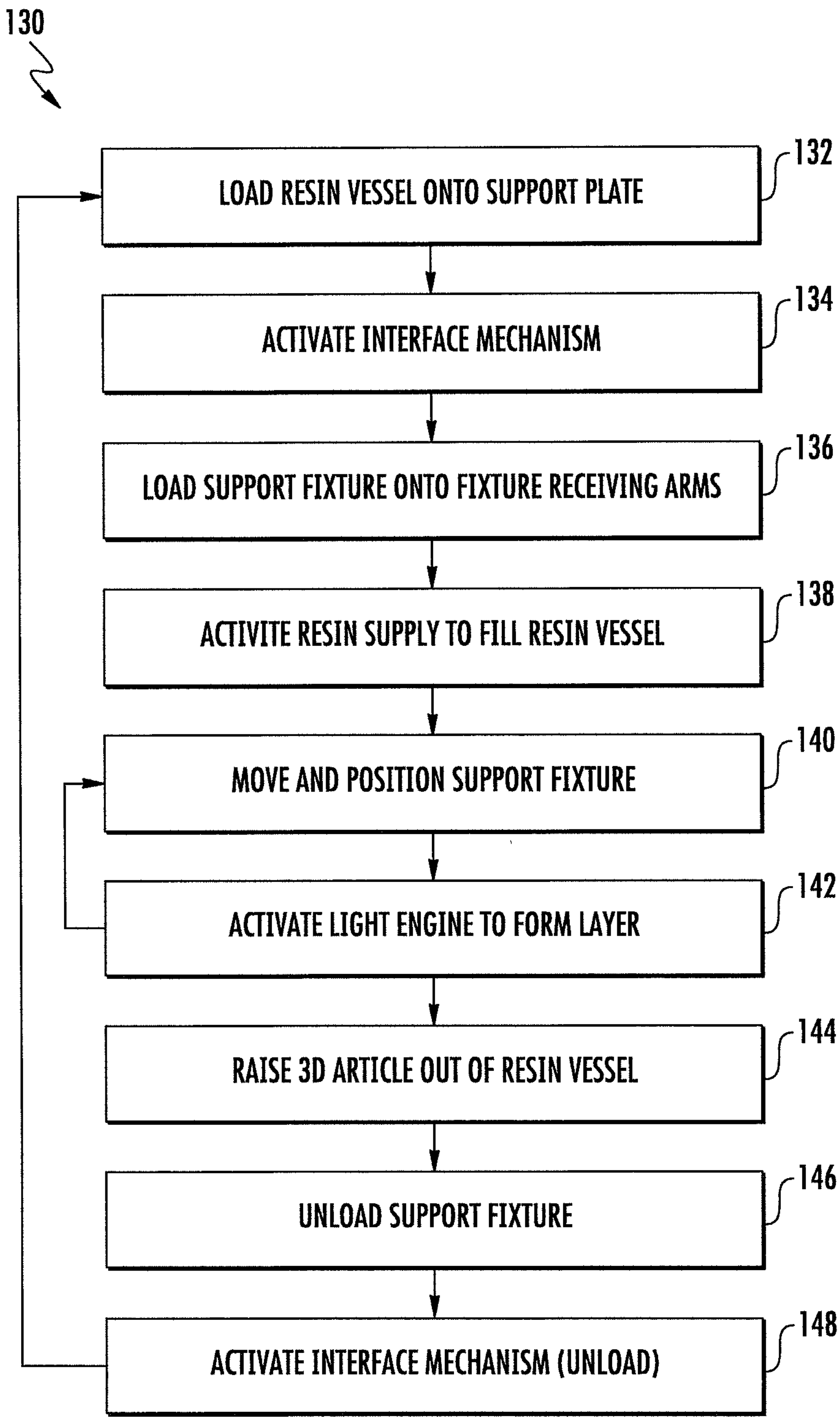
130
LOAD RESIN VESSEL ONTO SUPPORT PLATE
132
ACTIVATE INTERFACE MECHANISM
134
LOAD SUPPORT FIXTURE ONTO FIXTURE RECEIVING ARMS
136
ACTIVITE RESIN SUPPLY TO FILL RESIN VESSEL
138
MOVE AND POSITION SUPPORT FIXTURE
140
ACTIVATE LIGHT ENGINE TO FORM LAYER
142
RAISE 3D ARTICLE OUT OF RESIN VESSEL
144
UNLOAD SUPPORT FIXTURE
146
ACTIVATE INTERFACE MECHANISM (UNLOAD)
148

FIG. 6

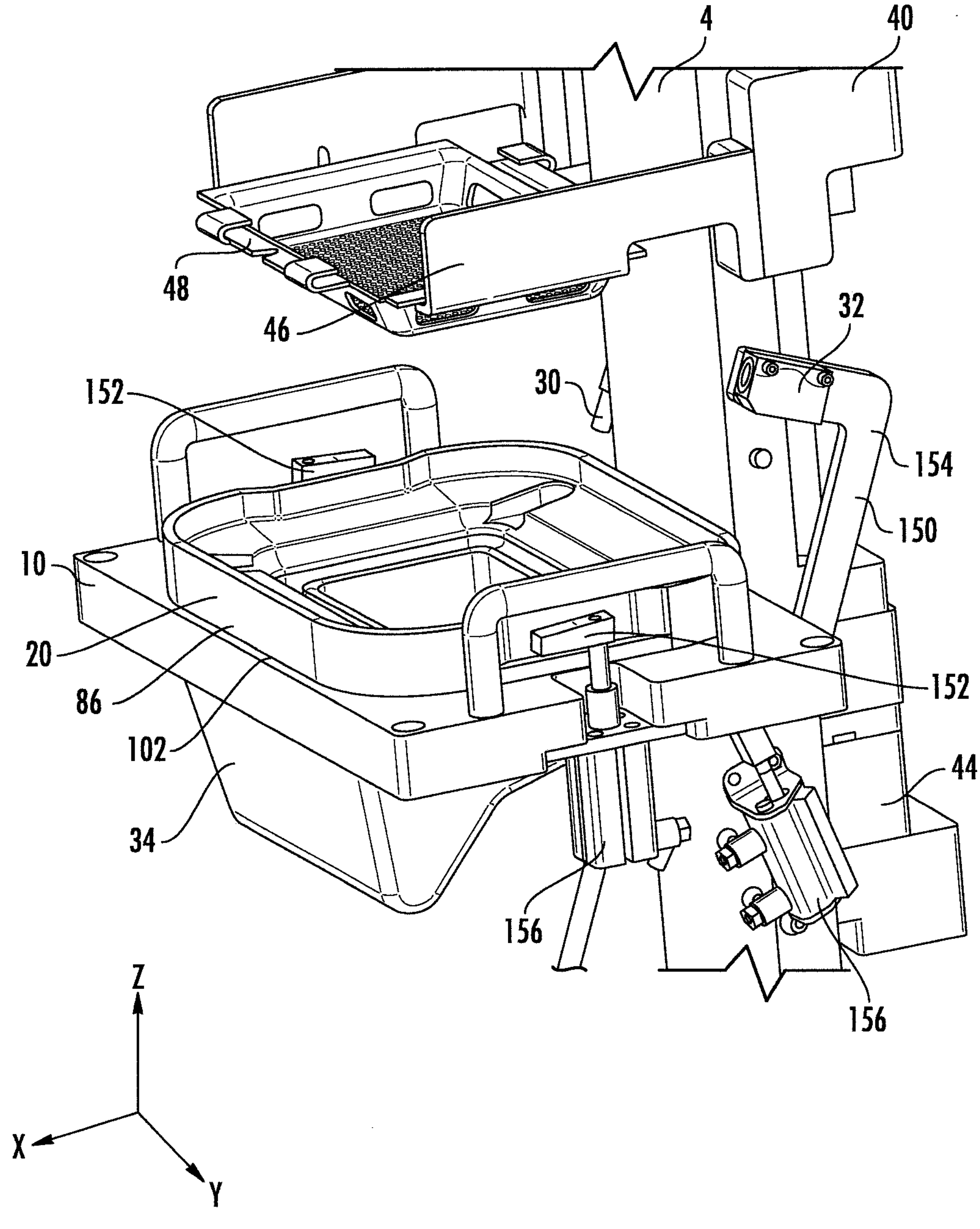


FIG. 7A

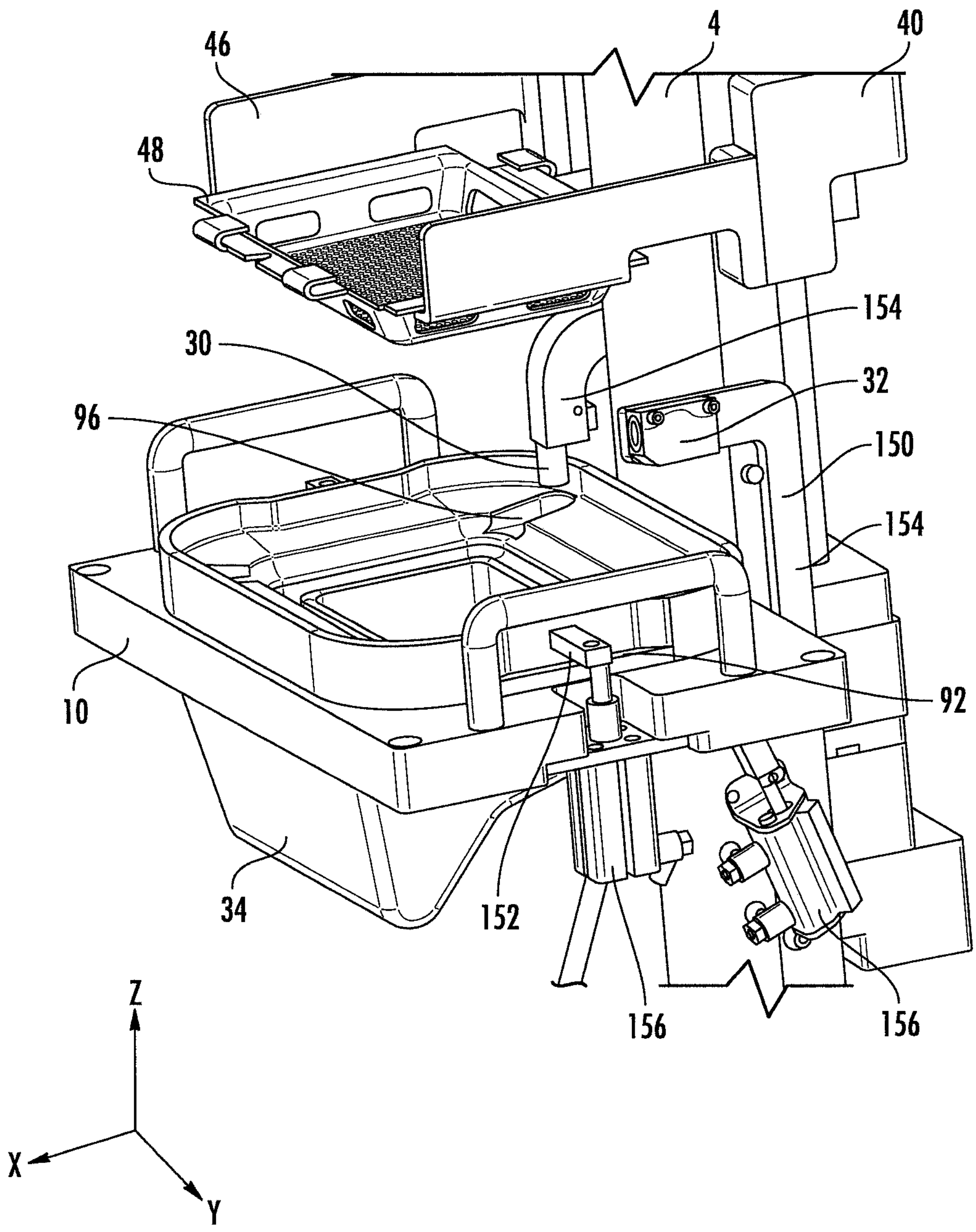


FIG. 7B

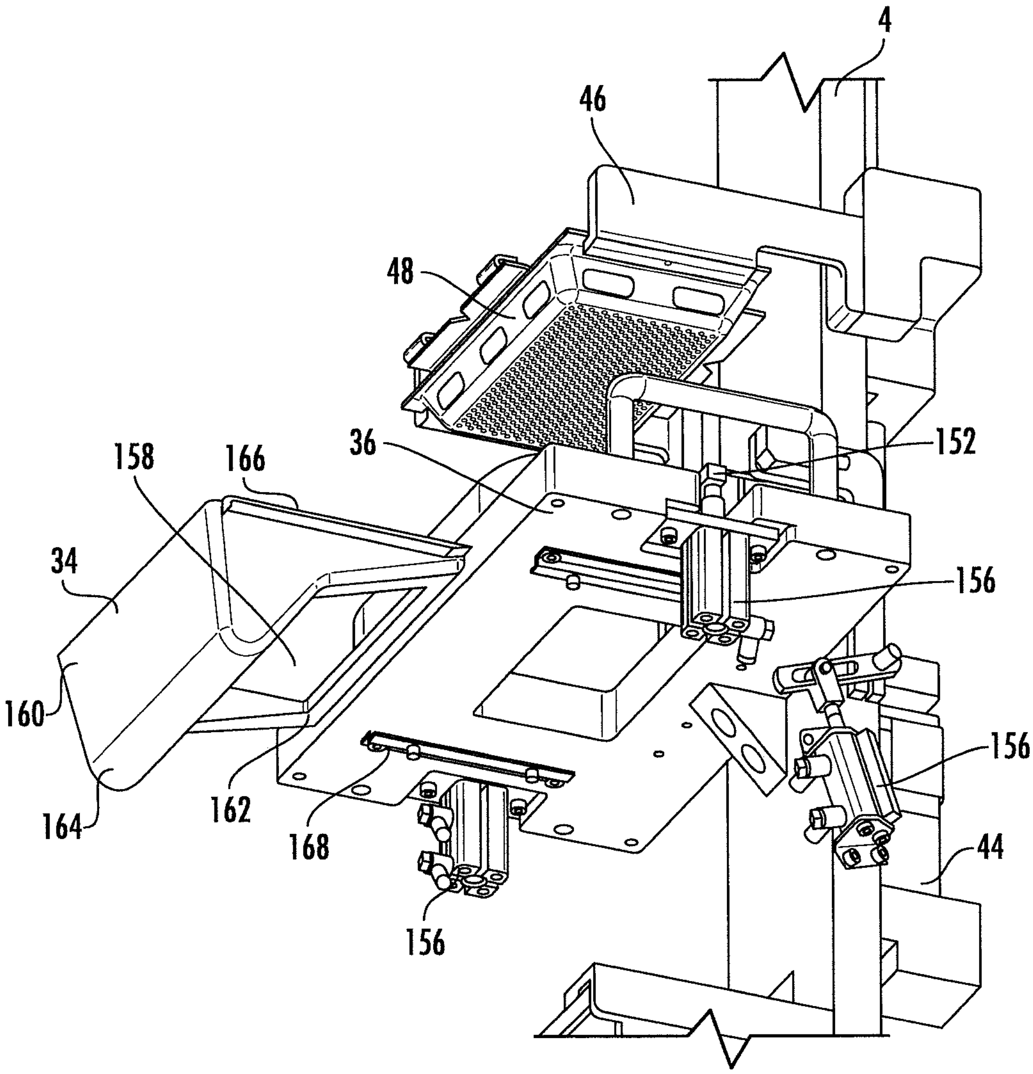


FIG. 7C

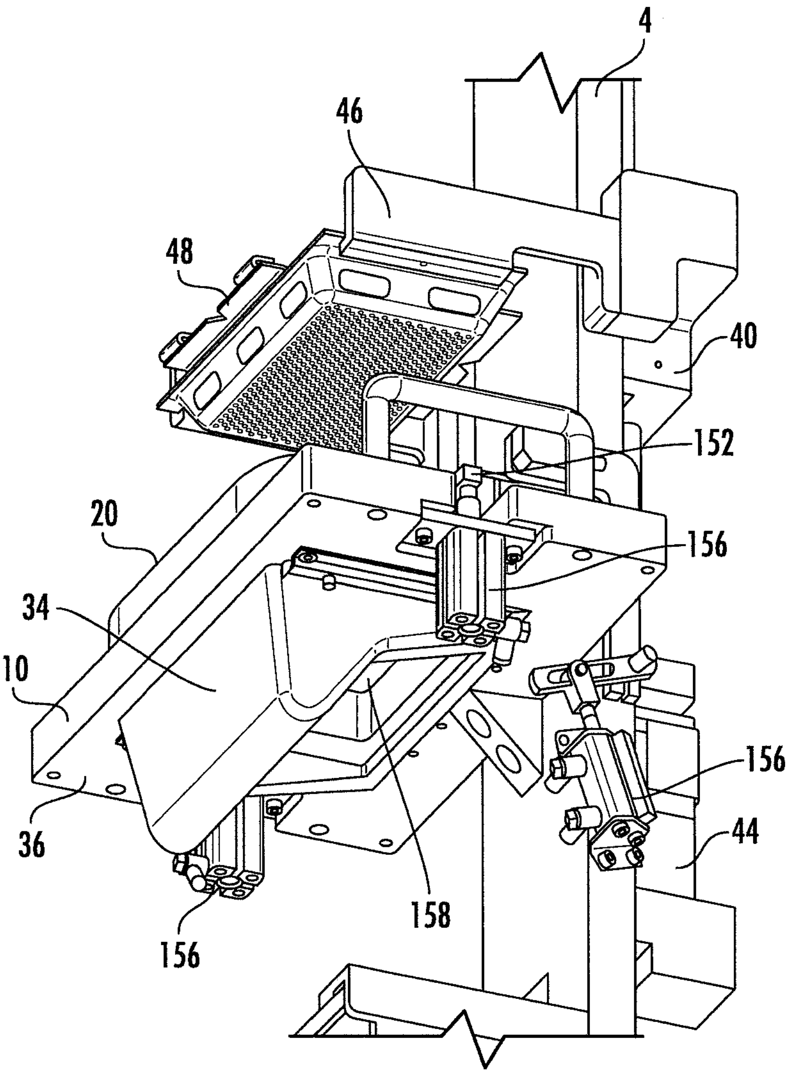


FIG. 7D

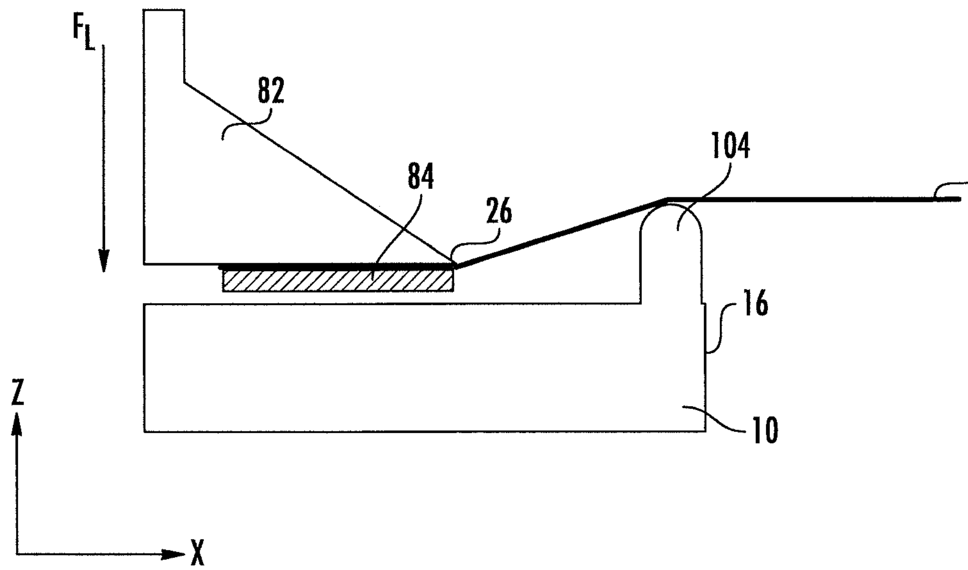


FIG. 8A

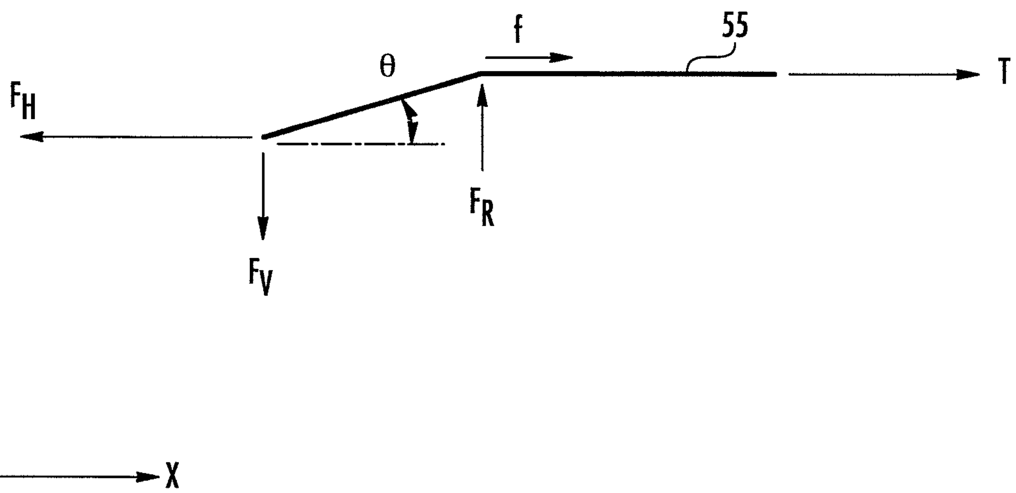


FIG. 8B

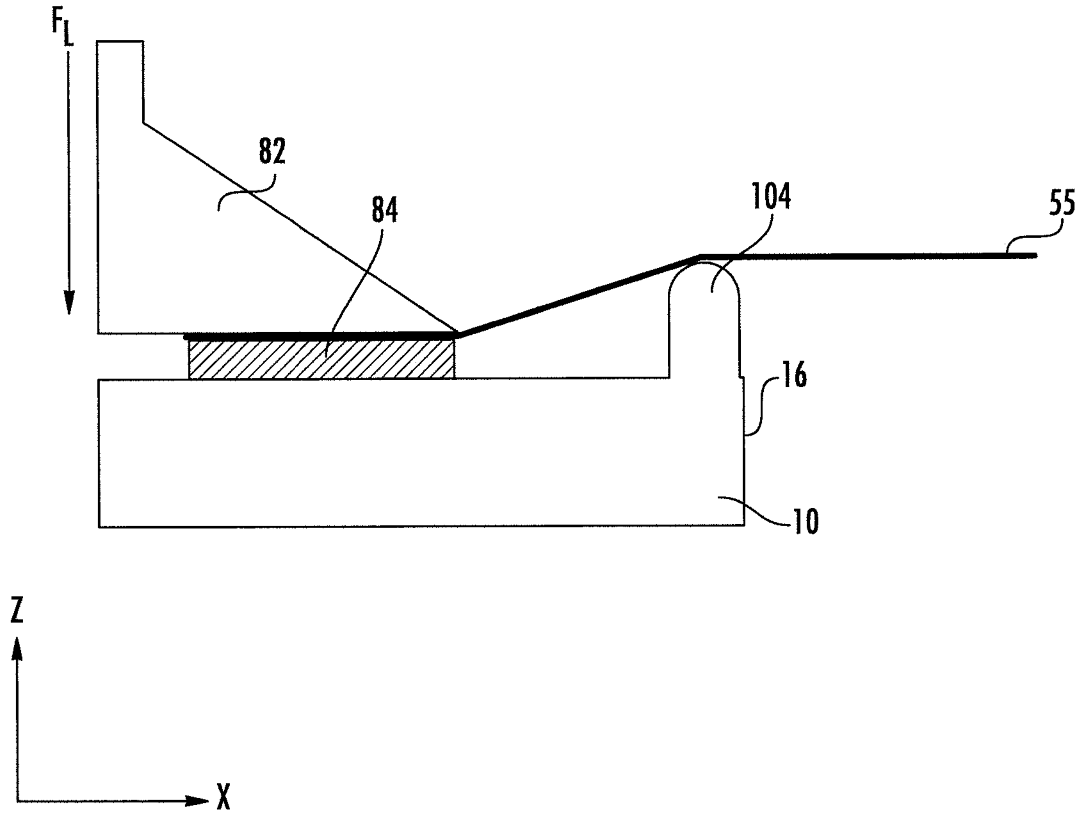


FIG. 8C

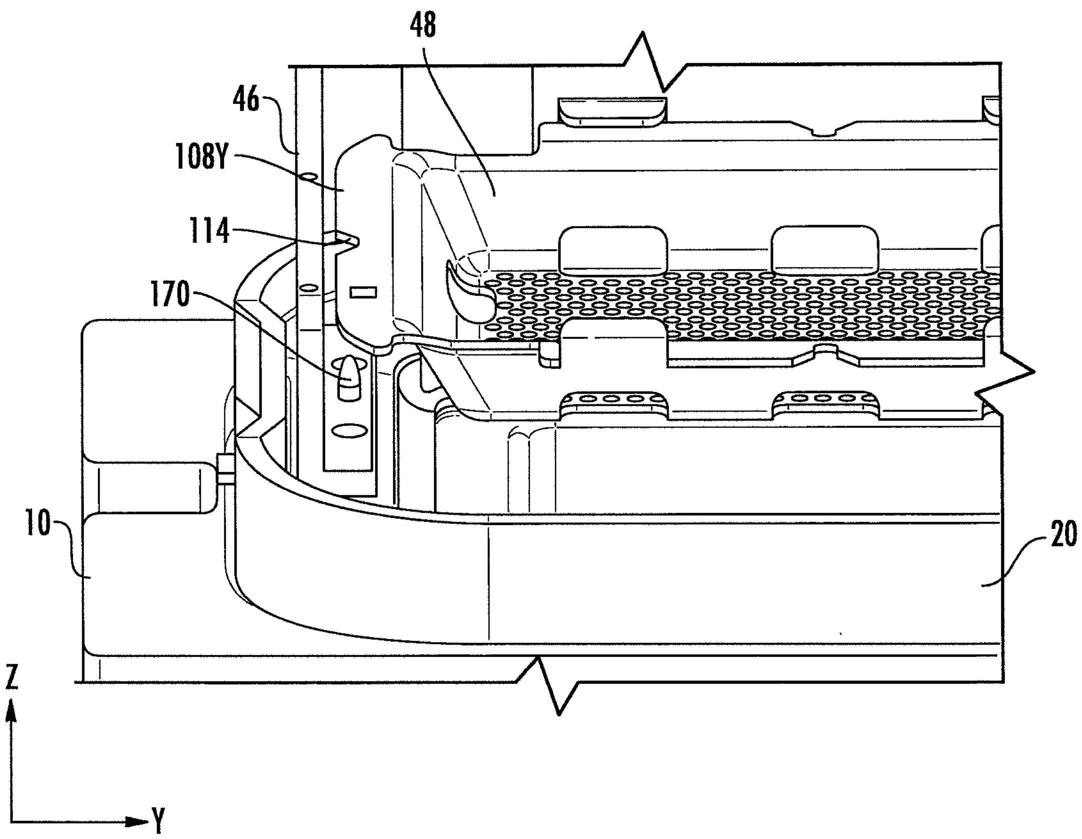


FIG. 9

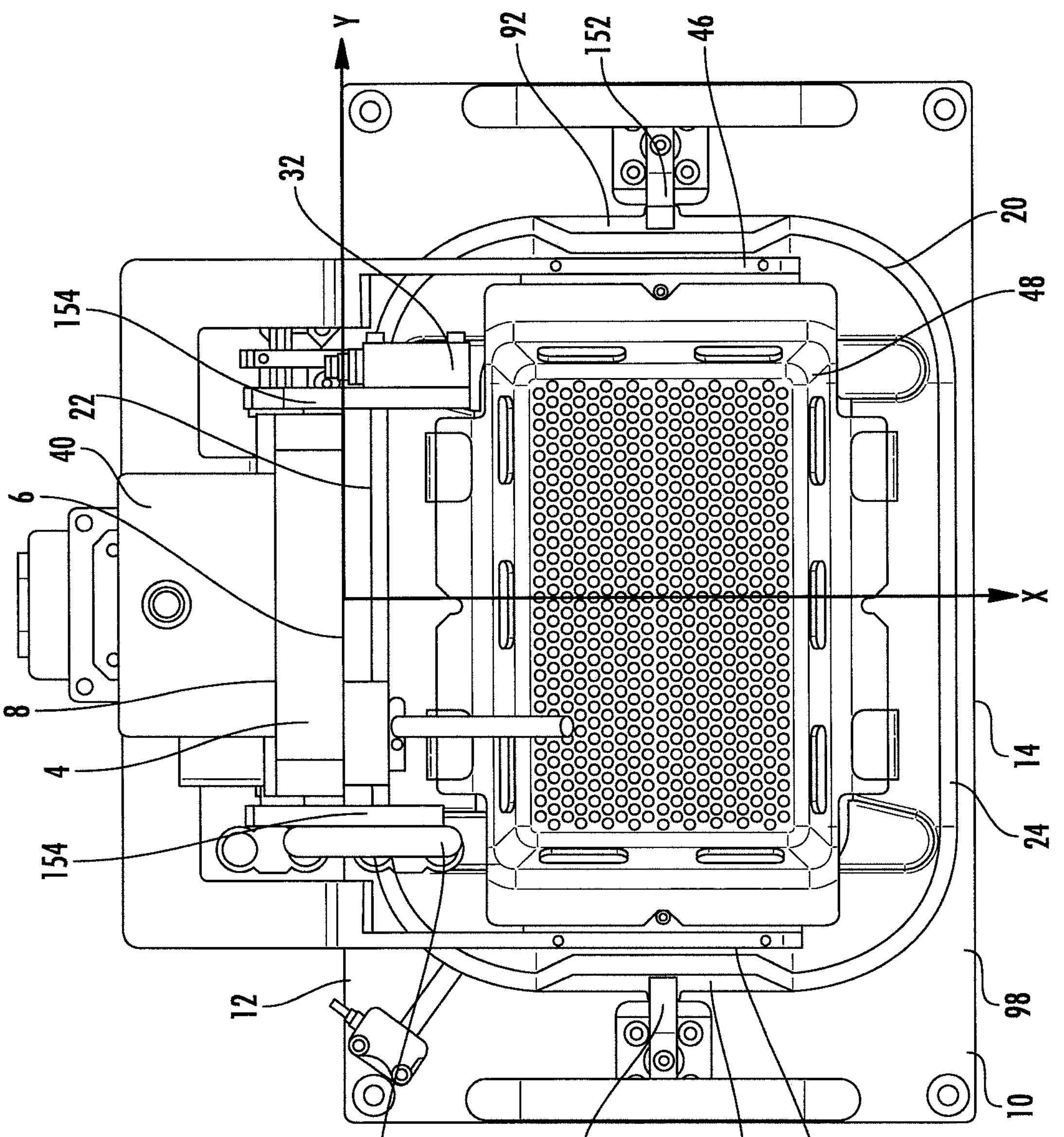


FIG. 10

# INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/033201

**A. CLASSIFICATION OF SUBJECT MATTER**
INV. B29C64/124 B29C64/357 B29C64/245 B29C64/223 B29C64/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
B29C B33Y

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | CN 204 894 534 U (PRINT RITE UNICORN IMAGE PRODUCTS CO LTD ZHUHAI) 23 December 2015 (2015-12-23) | 1,5-7, 13-15 |
| Y | figures 2, 3, 5 paragraphs [0035], [0036], [0039] | 2-4, 8-12, 16-18 |
| Y | CN 204 183 908 U (SHANGHAI LIANTAI 3D TECHNOLOGY CO LTD) 4 March 2015 (2015-03-04) figure 1 | 2-4 |
| Y | US 2015/375458 A1 (CHEN PENG-YANG [TW] ET AL) 31 December 2015 (2015-12-31) figure 6 | 8-10 |

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 30 August 2018 | 11/09/2018 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016 | Gasner, Benoit |

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y | DE 10 2012 011610 A1 (DAIMLER AG [DE]) 29 November 2012 (2012-11-29) figure 3 paragraph [0044] ----- | 11,16-18 |
| Y | WO 2014/130610 A2 (GLOBAL FILTRATION SYSTEMS DBA GULF FILTRATION SYSTEMS INC [US]) 28 August 2014 (2014-08-28) figure 2 ----- | 12 |

1

# INTERNATIONAL SEARCH REPORT

**Information on patent family members**

International application No
PCT/US2018/033201

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| CN 204894534 U | 23-12-2015 | NONE | |
| CN 204183908 U | 04-03-2015 | NONE | |
| US 2015375458 A1 | 31-12-2015 | CN 105196535 A | 30-12-2015 |
| | | TW 201600319 A | 01-01-2016 |
| | | US 2015375458 A1 | 31-12-2015 |
| DE 102012011610 A1 | 29-11-2012 | NONE | |
| WO 2014130610 A2 | 28-08-2014 | EP 2958719 A2 | 30-12-2015 |
| | | WO 2014130610 A2 | 28-08-2014 |