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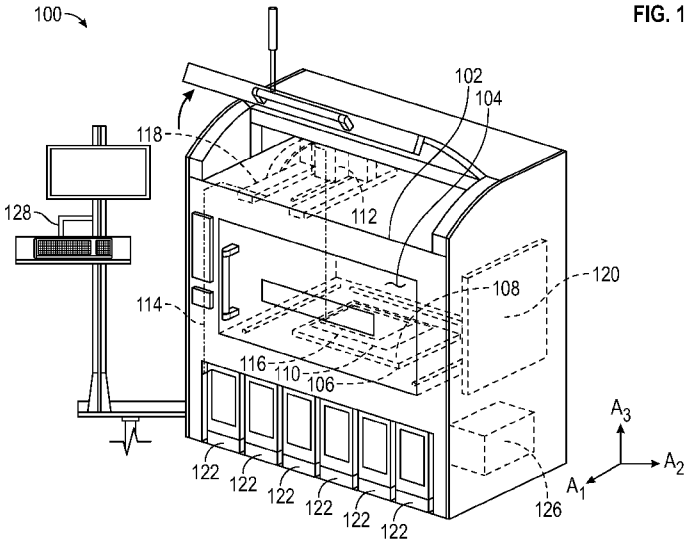
(54) Title: MAGNETIC SUPPORT BED FOR A 3D PRINTER

FIG. 1



(57) Abstract: A three-dimensional printer includes a support tray moveably fixed on a frame of the three-dimensional printer and configured to move in a Z-direction. An insulation sheet is provided adjacent to and supported by the support tray. A heating member is provided adjacent to and supported by the insulation sheet. A support bed is provided adjacent to the heating member and supported by the support tray, and a ferromagnetic build plate is provided adjacent to and supported by the support bed. The ferromagnetic build plate includes a pair of locator tabs that locate and align the ferromagnetic build plate on the support bed. The support bed includes a plurality of magnets that produce a magnetic force to hold the ferromagnetic build plate against a surface of the support bed.

WO 2023/086860 A1

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MAGNETIC SUPPORT BED FOR A 3D PRINTER

FIELD

[0001] The present disclosure relates generally to a support bed for constructing a three-dimensional printed part thereon.

BACKGROUND

[0002] The statements in this section merely provide background information related to the present disclosure and may or may not constitute prior art.

[0003] In three-dimensional printing, a three-dimensional object is formed by sequentially depositing layers of a material. Each layer of the material is supported by the layer of material underneath it and where it may not be possible to fully support the material, support structures are incorporated into the design that may be removed after printing is completed. Within the printer, the material is deposited on a build plate, which may be directly or indirectly heated. Ideally, the material adheres to the build plate during printing and then may be removed from the build plate after printing without damaging the printed three-dimensional object. Further, the build plate provides a flat surface to print on or a surface conforming to the geometry of the object that is to be printed.

[0004] To increase printer through-put, after forming a three-dimensional object on the build plate, the build-plate may be removed from the three-dimensional printer and replaced with a new build plate. Depending on the type of build plate used, removing the build plate may allow the plate to flex

or be conditioned in a process chamber, to facilitate removal of the printed object from the plate. The build plate is supported within the print chamber by a support bed. More specifically, the build plate is disposed on a support surface of the support bed. Various solutions have been developed to adhere a build plate to a support bed in a three-dimensional printer. Such solutions include the use of magnetic plates or releasable adhesives.

[0005] However, as the temperatures in the printer change, the support bed may warp. Warping of the support bed may lead to warping of the build plate or may cause the build plate to become improperly affixed to the support bed. Warping of the build plate or failure of the build plate to properly adhere to the support bed surface will likely result in printing defects.

[0006] Accordingly, while current solutions for improving flatness of the build surface and securing a removable build plate to a support bed of a three-dimensional printer are useful for their intended purpose, there is room in the art for an improved printer design and method for securing a build plate to a support bed.

SUMMARY

[0007] According to several aspects, a three-dimensional printer includes a support tray moveably fixed on a frame of the three-dimensional printer and configured to move in a Z-direction, an insulation sheet supported by the support tray, a heating member adjacent to and supported by the insulation sheet, a support bed adjacent to the heating member and supported by the support tray, and a ferromagnetic build plate adjacent to and supported by the support bed, wherein the ferromagnetic build plate includes a pair of locator tabs that locate and align the build plate on the support bed.

[0008] In another aspect of the present disclosure, the three-dimensional printer further includes a plurality of adjustable mounting assemblies.

[0009] In another aspect of the present disclosure, the plurality of adjustable mounting assemblies includes three adjustable mounting assemblies.

[0010] In another aspect of the present disclosure, one of the three adjustable mounting assemblies includes a first end for supporting the print bed and a second end fixed to the support tray.

[0011] In another aspect of the present disclosure, the first end of one of the three adjustable mounting assemblies for supporting the print bed includes a pair of opposing walls.

[0012] In another aspect of the present disclosure, the first end of one of the three adjustable mounting assemblies for supporting the print bed includes a hemispherical shaped surface.

[0013] In another aspect of the present disclosure, the first end of one of the three adjustable mounting assemblies for supporting the print bed includes a planar surface.

[0014] In another aspect of the present disclosure, the support bed further includes a first set of grooves and a second set of grooves and wherein the first set of grooves are perpendicular to the second set of grooves.

[0015] In another aspect of the present disclosure, the support bed further includes a plurality of magnets.

[0016] In another aspect of the present disclosure, the support bed further includes a plurality of apertures and wherein the apertures are disposed

in a surface of the support bed in a contact surface area defined by the first set of grooves and the second set of grooves.

[0017] In another aspect of the present disclosure, the three-dimensional printer includes at least one of the plurality of magnets is disposed in at least one of the plurality of apertures in the contact surface area. The high temperature magnets produce a magnetic force that holds a ferromagnetic build plate against a surface of the support bed.

[0018] In another aspect of the present disclosure, a method of printing a three-dimensional object with a three-dimensional printer includes moving a support tray in a Z-direction, wherein the support tray is moveably fixed on a frame of the three-dimensional printer, insulating the support tray with an insulation sheet adjacent to and supported by the support tray, supporting the printed object using a build plate, supporting the build plate with a support bed supported by the support tray, and heating the support bed with a heating member adjacent to and supported by the insulation sheet.

[0019] In another aspect of the present disclosure, the method further includes adjusting a flatness of the support bed using a plurality of adjustable mounting assemblies.

[0020] In another aspect of the present disclosure, the method further includes adjusting a flatness of the support bed includes using three adjustable mounting assemblies to adjust the flatness of the support bed.

[0021] In another aspect of the present disclosure, the method further includes adjusting a flatness of the support bed includes using one of the three adjustable mounting assemblies having a first end for supporting the support bed and a second end fixed to the support tray.

[0022] In another aspect of the present disclosure, the method further includes adjusting a flatness of the support bed includes using the first end of one of the three adjustable mounting assemblies for supporting the support bed having a pair of opposing walls.

[0023] In another aspect of the present disclosure, the method further includes adjusting a flatness of the support bed includes using the first end of one of the three adjustable mounting assemblies for supporting the support bed having a hemispherical shaped surface.

[0024] In another aspect of the present disclosure, the method further includes adjusting a flatness of the support bed includes using the first end of one of the three adjustable mounting assemblies for supporting the support bed includes a planar surface.

[0025] In another aspect of the present disclosure, the method further includes supporting the build plate with a support bed supported by the support tray further includes supporting the build plate with a support bed having a first set of grooves and a second set of grooves and wherein the first set of grooves are perpendicular to the second set of grooves.

[0026] In another aspect of the present disclosure, the method further includes supporting the build plate with a support bed supported by the support tray further includes supporting the build plate with a support bed wherein the support bed further includes a plurality of magnets.

[0027] In another aspect of the present disclosure, the method further includes supporting the build plate with a support bed supported by the support tray further includes supporting the build plate with a support bed having a plurality of apertures and wherein the apertures are disposed in a surface of the

support bed in a contact surface area defined by the first set of grooves and the second set of grooves.

[0028] Further areas of applicability will become apparent from the description provided herein. It should be understood that the description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

DRAWINGS

[0029] The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

[0030] FIG. 1 is a perspective view of a three-dimensional printer illustrated according to an exemplary embodiment;

[0031] FIG. 2 is a perspective view of a support tray for supporting and moving the support bed within the process chamber along the third axis A3 illustrated according to an exemplary embodiment;

[0032] FIG. 3 is a perspective view of an insulation sheet illustrated according to an exemplary embodiment;

[0033] FIG. 4 is a perspective view of a heating member illustrated according to an exemplary embodiment;

[0034] FIGS. 5A and 5B a perspective view of a support surface of a support bed is illustrated in FIG. 5A and a bottom surface of support bed is illustrated in FIG. 5B according to an exemplary embodiment;

[0035] FIG. 6 is a perspective view of a build plate illustrated according to an exemplary embodiment;

[0036] FIGS. 7A and 8B is a perspective view of a mounting assembly in FIG. 7A and in a cross-sectional view in FIG. 7B illustrated according to an exemplary embodiment;

[0037] FIGS. 8A and 8B is a perspective view of another (a second) mounting assembly in FIG. 8A and in a cross-sectional view in FIG. 8B illustrated according to an exemplary embodiment;

[0038] FIGS. 9A and 9B is a perspective view of yet another (a third) mounting assembly in FIG. 9A and in a cross-sectional view in FIG. 9B illustrated according to an exemplary embodiment; and

[0039] FIG. 10 is a perspective view of a magnet illustrated according to an exemplary embodiment.

DETAILED DESCRIPTION

[0040] The following description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses.

[0041] An aspect of a three-dimensional printer 100 is illustrated in FIG. 1. The three-dimensional printer 100 generally includes an enclosure 102 defining a process chamber 104 and a support bed 106 supported within the process chamber 104. The support bed 106 includes a support surface 108 onto which a build plate 110 is placed. The three-dimensional printer 100 further includes a print head 112, which deposits filament 114 onto the build plate 110 to form the three-dimensionally printed object 116. The print head 112 is supported relative to the build plate 110 on an x,y-axis gantry 118 allowing the print head 112 to move in a plane defined by a first axis A1 and a

second axis A2. The support bed 106 is moved relative to the print head 112 by a z-axis gantry 120 allowing the support bed 106 to move along a third axis A3 orthogonal to the plane defined by the first axis A1 and second axis A2. In further aspects, the print head 112 may be moved along the z-axis and the support bed 106 may be moved along the x,y-axis. Filament 114 is stored in one or more canisters 122 and provided to the print head 112 by a filament drive system 124. A controller 128 is provided to control the various functions of the three-dimensional printer 100.

[0042] Referring to FIG. 2, a perspective view of a support tray 150 for supporting and moving the support bed 106 within the process chamber 104 along the third axis A3 is illustrated. Support tray 150 includes a pair of side support brackets 152 and 154. Side support brackets 152 and 154, have a top edge surface 156 and 158 that support for rigid mounting a top support bracket 160. Top support bracket 160 is attached to the top edge surfaces 156, 158 of side support brackets 152 and 154 by fasteners such as screws and the like. Additional rigidity is imparted to the support tray 150 by a cross support bracket 162. Side support brackets 152 and 154 are each attached to cross support bracket 162 by fasteners such as screws and the like. Additionally, side support brackets 152 and 154 have ends 164 and 166 that are configured to engage the Z-axis gantry 120 drive system (not shown) in the process chamber 104 which moves the support tray 150 in the A_3 direction within the process chamber 104. A plurality of mounting assemblies 170, 172 and 174 are attached to support tray 150. More specifically, mounting assembly 170 is attached with fasteners or the like to side support bracket 152, mounting assembly 172 is attached with fasteners or the like to side support bracket 154, and mounting

assembly 174 is attached with fasteners or the like to cross support bracket 162. As will be described in greater detail below, mounting assemblies 170, 172 and 174 are configured to mount the support bed 106 to the support tray 150.

[0043] Referring to FIG. 3, an insulation sheet 180 is illustrated. Insulation sheet 180 is preferably made of a material that impedes the transmission of heat to the support tray 150. For example, insulation sheet 180 is made of alumina silica ceramic fiber. Insulation sheet 180 has three apertures 182, 184 and 186. Aperture 182 is configured to allow mounting assembly 170 to pass therethrough. Aperture 184 is configured to allow mounting assembly 172 to pass therethrough. Aperture 186 is configured to allow mounting assembly 174 to pass therethrough.

[0044] Referring to FIG. 4, a heating member 190 is illustrated. Heating member 190 is a thermally conductive sheet having at least one or more resistive heating element and one or more thermal detectors affixed thereto. In aspects, the resistive heating elements provide a watt density in the range of 0.1 Watts per square centimeter to 0.3 Watts per square centimeter, including all values and ranges therein. The heating member 190 further includes a plurality of apertures 192, 194 and 196. Aperture 192 is configured to allow mounting assembly 170 to pass therethrough. Aperture 194 is configured to allow mounting assembly 172 to pass therethrough. Aperture 196 is configured to allow mounting assembly 174 to pass therethrough.

[0045] Referring to FIGS. 5A and 5B, support surface 108 of support bed 106 is illustrated in FIG. 5A and a bottom surface 202 of support bed 106 is illustrated in FIG. 5B. Support bed 106 includes a plurality of apertures 210

that partially penetrate the thickness of the support bed 106. Apertures 210 are configured to hold a ring-shaped magnet 212 shown in FIG. 10. Ring-shaped magnet 212 is preferably made of a high temperature magnet material, such as samarium cobalt (SmCo). The operating temperature of the process chamber 104 is between 20 degrees C and 200 degrees C. Thus, the magnets 212 and support bed 106 are configured to withstand the operating temperature range and maintain relative flatness of the support bed over the operating temperature range. Further, the support bed 106 includes a number of grooves 214 defined in the support surface 108. With reference to FIG. 5A, in aspects, a first set of grooves 220 are provided across the support surface 200 of the support bed 106 at a given interval, wherein the interval is in the range of 1 cm to 10 cm, including all values and ranges therein and in one example 61 mm and 71 mm spacing. A second set of grooves 222 are provided at an angle A to the first set of grooves 220, wherein the angle A is in the range of 30 to 120 degrees, including all values and ranges therein, and is preferably 90 degrees (i.e., the second set of grooves 222 is perpendicular to the first set of grooves 220). The intersecting first and second set of grooves 220 and 222 define a contact surface area 224 that includes at least one aperture 210. In addition, and with continuing reference to FIG. 5A, the support bed 106 is formed of MIC6 or ATP5 precision cast aluminum, assuming a coefficient of thermal expansion of 0.000024 m/mK. Further, the support surface 108 of the support bed 106 exhibits a flatness in the range of 0.00 mm to 0.05 mm over the entire length and width of the bed 106, including all values and ranges therein, such as less than 200 microns, at elevated temperatures of up to 200 degrees C, regardless of any other features such as the grooves defined in the support surface 108.

Additionally support bed 106 further includes side rails 226 integrally formed on each side 228 of the support bed 106. Side rails 226 have a T-shaped cross-section and are configured to add rigidity to the support bed 106 to prevent warpage of the bed 106 and maintain flatness. With continuing reference to FIG. 5B, the bottom surface 202 includes three mounting features 250, 252, and 254 that each protrude from bottom surface 202. Mounting feature 250 has a square or rectangular profile 260 that mates with an end 171 of mounting assembly 170. Mounting feature 252 has a hemispherical profile 262 that mates with an end 173 of mounting assembly 172. Mounting feature 254 has a planar surface 264 that mates with an end 173 of mounting assembly 172.

[0046] Referring to FIG. 6, the build plate 110 is illustrated. Build plate 110 is a thin plate have a profile that generally conforms to the profile of the support bed 106. In an aspect, the build plate is made of spring steel or similar material that has flexibility and may be deformed but returns to the original shape and flatness. Importantly build plate 110 is made of a ferromagnetic material in the form of solid material, a coating or a composite made of a laminate of a polymer and a metal. Build plate 110 has a pair of locator tabs 270 and 272 located and protruding from a side 274 of the build plate 110. Locator tabs 270 and 272 are configured to engage locating features 271 and 273 on the support bed 106 to ensure that build plate 110 is oriented correctly on the support bed 106. Additionally, build plate 110 had a pair of tabs 278 and 280 that are located and protrude from a side 282 of the build plate 110 opposite the side 274. Tabs 278 and 280 are coated with a thermally insulating material such as silicone or the like. Tabs 278 and 280 function as handles or grab areas that can be grasped by a user or operator of the three-

dimensional printer 100 to remove the build plate 110 from the process chamber 104.

[0047] The magnetic forces produced by the high temperature magnets 212 fixed to support bed 106 attract the ferromagnetic material of the build plate 110. Through the magnetic attraction of the build plate 110 to the support bed 106, the build plate 110 is securely held to the support bed. The support bed 106 having the plurality of magnets 212 disposed in apertures 210 over the support surface 108 provides a magnet density of one magnet per 44 cm^2.

[0048] Referring to FIG. 7A and 7B, the mounting assembly 170 is illustrated in a perspective view in FIG. 7A and in a cross-sectional view in FIG. 7B. Mounting assembly 170 includes a fixed member 300 fixedly mounted to the support tray 150 and a movable member 302 slidably mounted to the support tray 150. Fixed member 300 includes a pair of mounting apertures 304 and 306. Mounting apertures 304 and 306 are configured to receive fasteners such as screws and the like to securely attach fixed member 300 to the support tray 150. In a non-limiting example, fixed member 300 is attached to side support bracket 152 using the mounting apertures 304 and 306. Movable member 302 is slidably mounted to the support tray 150 via a pair of slots 308 and 310. Slots 308 and 310 are configured to receive fasteners such as screws and the like to slidably attach movable member 302 to the side support bracket 152 of the support tray 150. Moreover, end 171 of mounting assembly 170 has a pair of opposing walls 312 and 314 that engage with and constrains a pair of walls formed in the square or rectangular profile 260 of mounting feature 250. Additionally mounting assembly 170 includes a pin 320 that is captured at a first

end 322 for rotation in the fixed member 300. Pin 320 has a second end 324 that is threaded to threadingly engage a threaded shaft 326 formed in movable member 302. Accordingly, in operation, rotation of pin 320 moves movable member 302 farther away or closer to fixed member 300. Thus, by operation or rotation of pin 320 the support bed 106 that is attached to mounting assembly 170 may be adjusted to ensure flatness of the support bed 106.

[0049] Referring to FIG. 8A and 8B, the mounting assembly 172 is illustrated in a perspective view in FIG. 8A and in a cross-sectional view in FIG. 8B. Mounting assembly 172 includes a fixed member 400 fixedly mounted to the support tray 150 and a movable member 402 slidably mounted to the support tray 150. Fixed member 400 includes a pair of mounting apertures 404 and 406. Mounting apertures 404 and 406 are configured to receive fasteners such as screws and the like to securely attach fixed member 400 to the support tray 150. In a non-limiting example, fixed member 400 is attached to side support bracket 154 using the mounting apertures 404 and 406. Movable member 402 is slidably mounted to the support tray 150 via a pair of slots 408 and 410. Slots 408 and 410 are configured to receive fasteners such as screws and the like to slidably attach movable member 402 to the side support bracket 154 of the support tray 150. Moreover, end 173 of mounting assembly 172 has a flat mounting surface 412 that engages with mounting feature 254. Additionally mounting assembly 172 includes a pin 420 that is captured at a first end 422 for rotation in the fixed member 400. Pin 320 has a second end 324 that is threaded to threadingly engage a threaded shaft 426 formed in movable member 402. Accordingly, in operation, rotation of pin 420 moves movable member 402 farther away or closer to fixed member 400. Thus, by operation

or rotation of pin 420 the support bed 106 that is attached to mounting assembly 172 may be adjusted to ensure flatness of the support bed 106.

[0050] Referring to FIG. 9A and 9B, the mounting assembly 174 is illustrated in a perspective view in FIG. 9A and in a cross-sectional view in FIG. 9B. Mounting assembly 174 includes a fixed member 500 fixedly mounted to the support tray 150. Fixed member 500 includes a pair of mounting apertures 504 and 506. Mounting apertures 504 and 506 are configured to receive fasteners such as screws and the like to securely attach fixed member 500 to the support tray 150. In a non-limiting example, fixed member 500 is attached to cross support bracket 162 using the mounting apertures 504 and 506. Moreover, at end 175 of mounting assembly 174 a hemispherical surface or bowl-shaped surface 512 is formed therein. Bowl shaped surface 512 is configured to engage with mounting feature 252. Accordingly, bowl shaped surface 512 and mounting feature 252 allows for movement of the support bed 106 in both the x and y directions but not in the z direction.

[0051] As will be easily understood from the above disclosure the insulation sheet 180 is first placed on the support tray 150 thereafter the heating member 190 is placed on insulation sheet 180. The support bed 106 is placed adjacent and on top of heating member 190. As previously described build plate 110 is located on support bed 106 and is attracted thereto by magnetic forces created by magnets 212 to maintain flatness of the build plate. This assembly of the present disclosure offers several advantages. These include allows for easy installation, alignment and removal of the build plate 110 and the printed object printed thereon, allows for wide range of process chamber 104 working temperatures, allows for a wide range of materials that may be

bonded to the ferromagnetic build plate 110, the support bed 106 allows the build plate 110 to lift off the surface 108 of the support bed 106 with minimal movement of the build plate 110 along the x-y axis, design of support bed 106 as described above provides straightness and flatness across a wide range of temperatures, and the three-point mounting and leveling features provided by the mounting assemblies 170, 172 and 174 allow for controlled slip of the build plate 110 along the x-y axis while maintaining positional repeatability and allowing for thermal expansion and minimizing distortion of the build plate 110. Moreover, the above-described assembly provides a less complex, less costly and more reliable method to secure the build plate 110 to the support bed 106. Advantageously, even if during the printing process the build plate 110 is lifted off the surface 108 of the support bed 106 the magnetic forces produced by magnets 212 will minimize movement of the build plate 110 in the x-y direction.

[0052] The description of the present disclosure is merely exemplary in nature and variations that do not depart from the gist of the present disclosure are intended to be within the scope of the present disclosure. Such variations are not to be regarded as a departure from the spirit and scope of the present disclosure.

CLAIMS

What is claimed is:

1. A three-dimensional printer comprising:

a support tray moveably fixed on a frame of the three-dimensional printer and configured to move in a Z-direction;

an insulation sheet supported by the support tray;

a heating member adjacent to and supported by the insulation sheet;

a support bed adjacent to the heating member and supported by the support tray; and

a ferromagnetic build plate adjacent to and supported by the support bed, wherein the ferromagnetic build plate includes a pair of locator tabs that locate and align the ferromagnetic build plate on the support bed.

2. The three-dimensional printer of claim 1, further including a plurality of adjustable mounting assemblies.

3. The three-dimensional printer of claim 2, wherein the plurality of adjustable mounting assemblies includes three adjustable mounting assemblies.

4. The three-dimensional printer of claim 3, wherein one of the three adjustable mounting assemblies includes a first end for supporting the support bed and a second end fixed to the support tray.

5. The three-dimensional printer of claim 4, wherein the first end of one of the three adjustable mounting assemblies for supporting the support bed includes a pair of opposing walls.

6. The three-dimensional printer of claim 4, wherein the first end of one of the three adjustable mounting assemblies for supporting the support bed includes a hemispherical shaped surface.

7. The three-dimensional printer of claim 4, wherein the first end of one of the three adjustable mounting assemblies for supporting the support bed includes a planar surface.

8. The three-dimensional printer of claim 4, wherein the support bed further includes a first set of grooves and a second set of grooves and wherein the first set of grooves are perpendicular to the second set of grooves.

9. The three-dimensional printer of claim 8, wherein the support bed further includes a plurality of magnets that produce a magnetic force that holds the ferromagnetic build plate to a surface of the support bed.

10. The three-dimensional printer of claim 9, wherein the support bed further includes a plurality of apertures and wherein the apertures are disposed in a surface of the support bed in a contact surface area defined by the first set of grooves and the second set of grooves.

11. The three-dimensional printer of claim 10, wherein at least one of the plurality of magnets is disposed in at least one of the plurality of apertures in the contact surface area.

12. A method of printing a three-dimensional object with a three-dimensional printer, the method comprising:

moving a support tray in a Z-direction, wherein the support tray is moveably fixed on a frame of the three-dimensional printer;

insulating the support tray with an insulation sheet adjacent to and supported by the support tray;

supporting the three-dimensional object using a build plate;

supporting the build plate with a support bed supported by the support tray; and

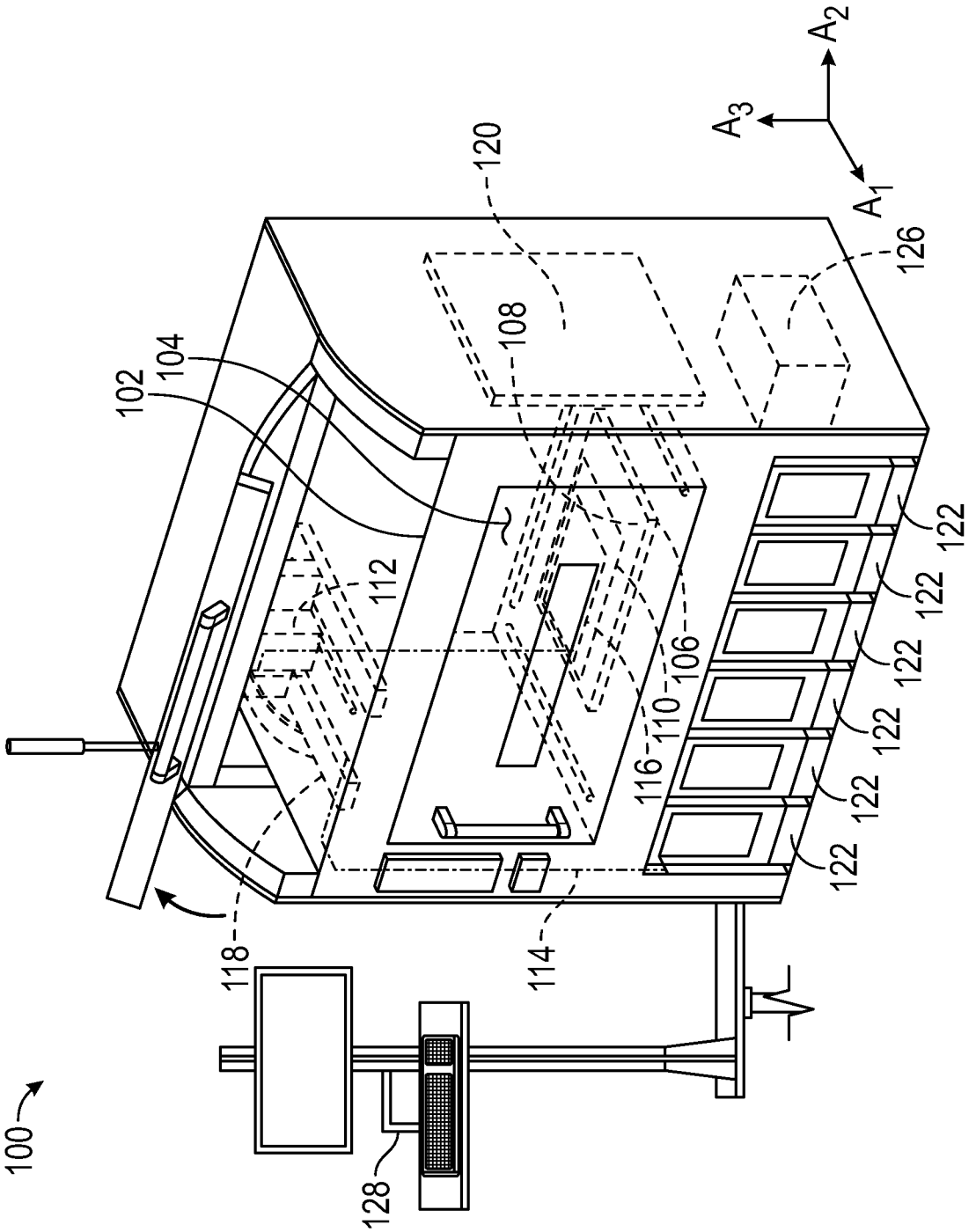
heating the support bed with a heating member adjacent to and supported by the insulation sheet.

13. The method of claim 12 further comprising adjusting a flatness of the support bed using a plurality of adjustable mounting assemblies, wherein adjusting a flatness of the support bed includes using one of three adjustable mounting assemblies having a first end for supporting the support bed and a

second end fixed to the support tray, wherein the first end of a first one of the three adjustable mounting assemblies has a pair of opposing walls, the first end of a second one of the three adjustable mounting assemblies has a hemispherical shaped surface, and the first end of a third one of the three adjustable mounting assemblies includes a planar surface.

14. The method of claim 12, wherein supporting the build plate with a support bed supported by the support tray further includes supporting the build plate with a support bed having a first set of grooves and a second set of grooves and wherein the first set of grooves are perpendicular to the second set of grooves, and wherein apertures are disposed in a surface of the support bed in a contact surface area defined by the first set of grooves and the second set of grooves.

15. The method of claim 12, wherein supporting the build plate with a support bed supported by the support tray further includes supporting the build plate with a support bed wherein the support bed further includes a plurality of magnets.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A3
A1
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FIG. 1

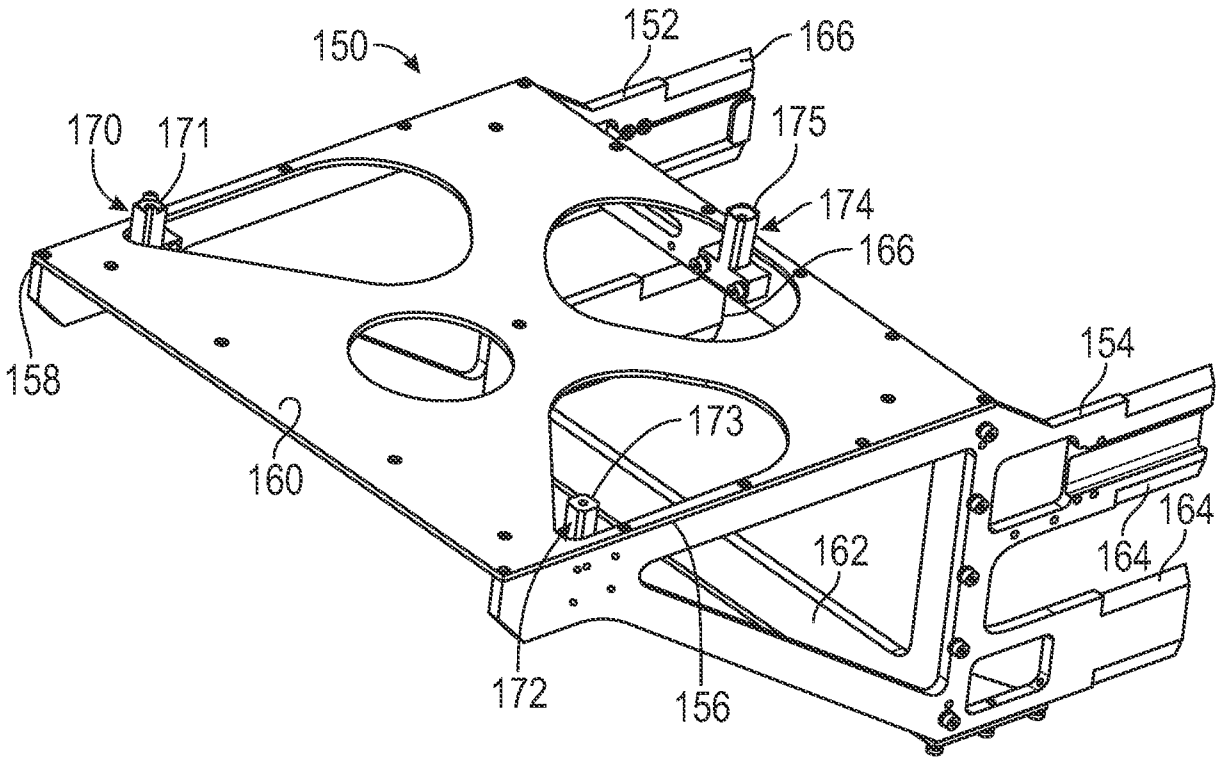
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FIG. 2

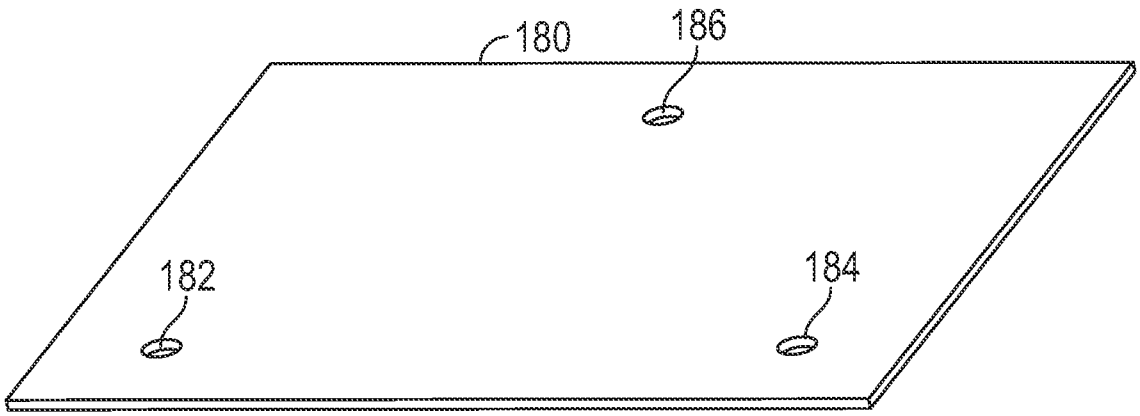
180
186
182
184

FIG. 3

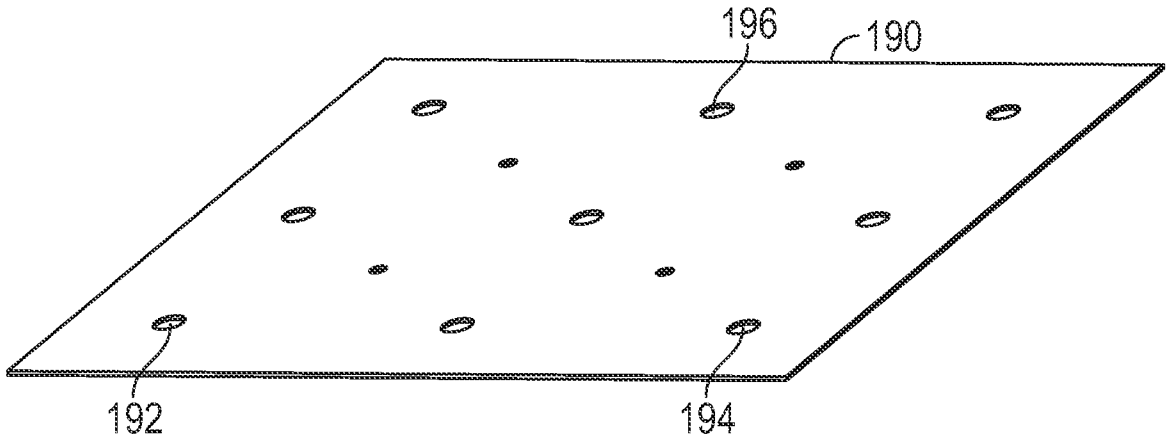
196
190
192
194

FIG. 4

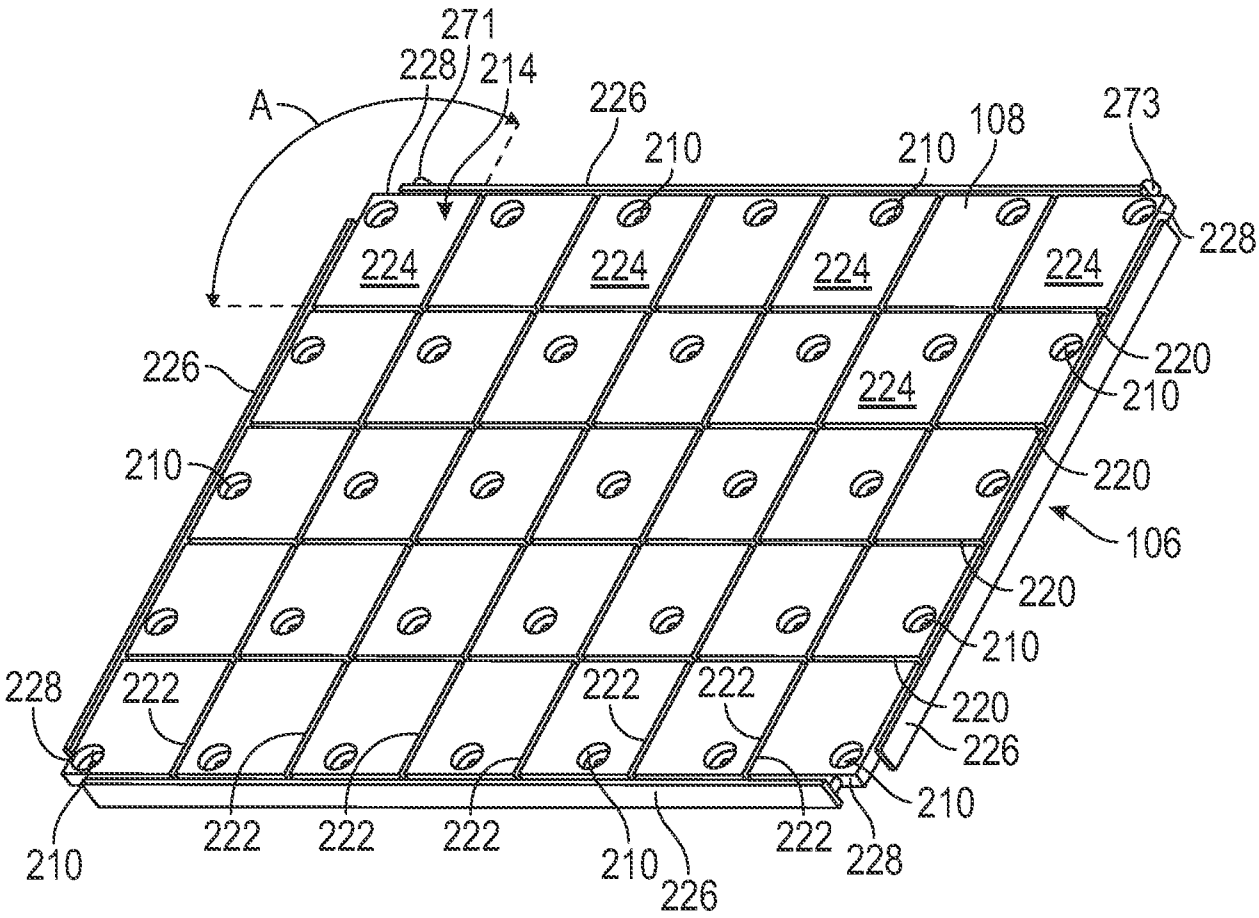
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FIG. 5A

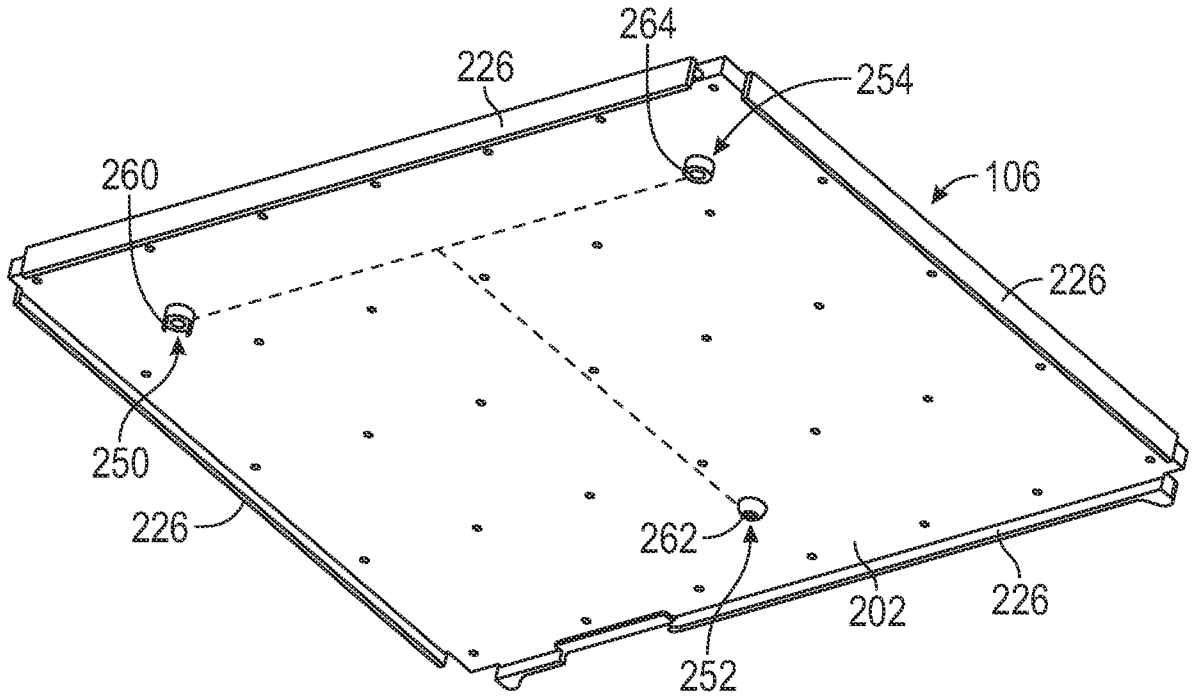
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FIG. 5B

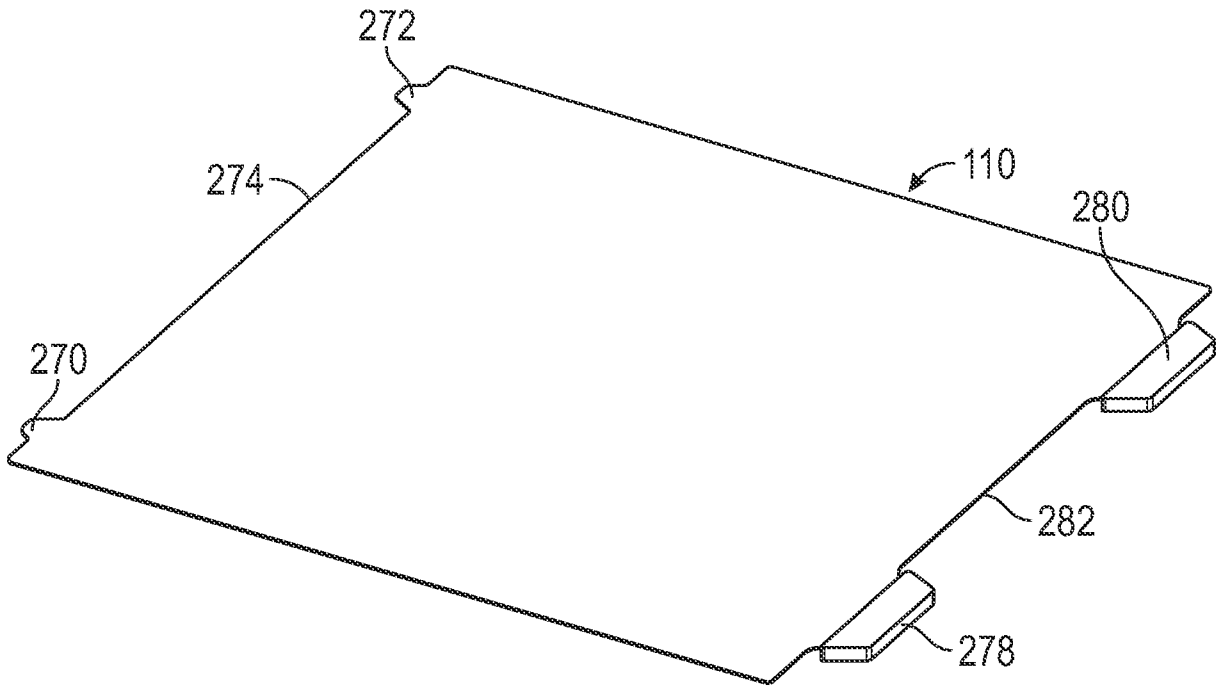
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FIG. 6

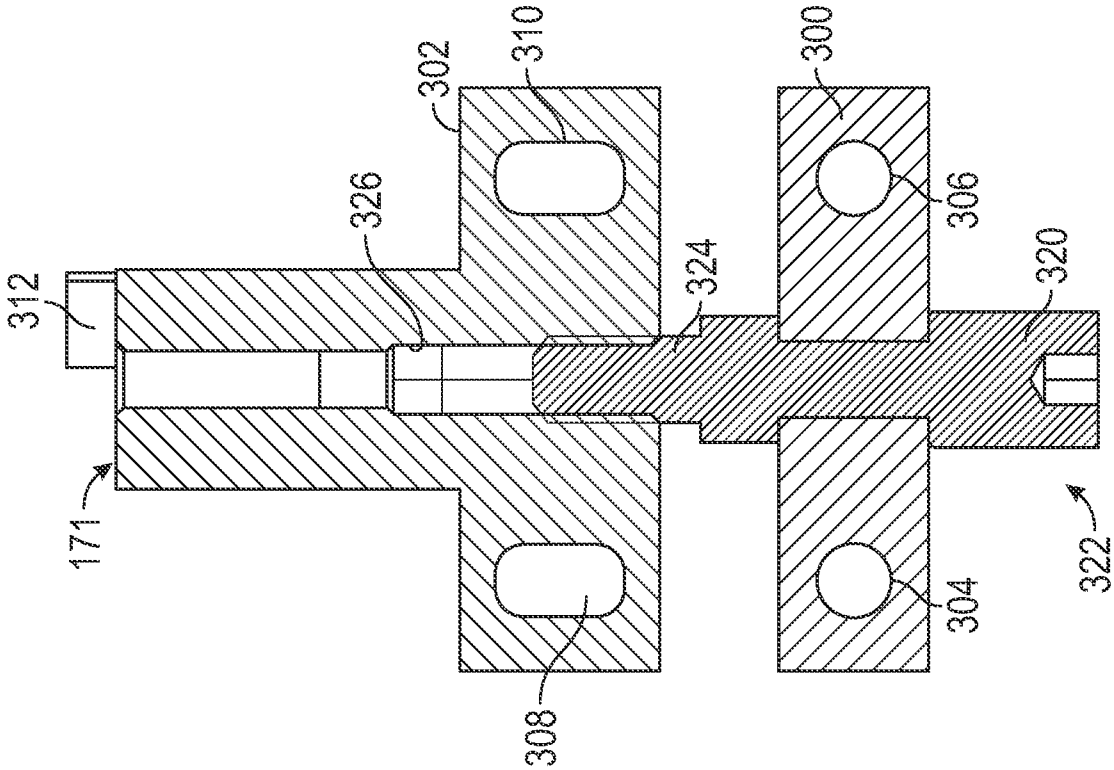
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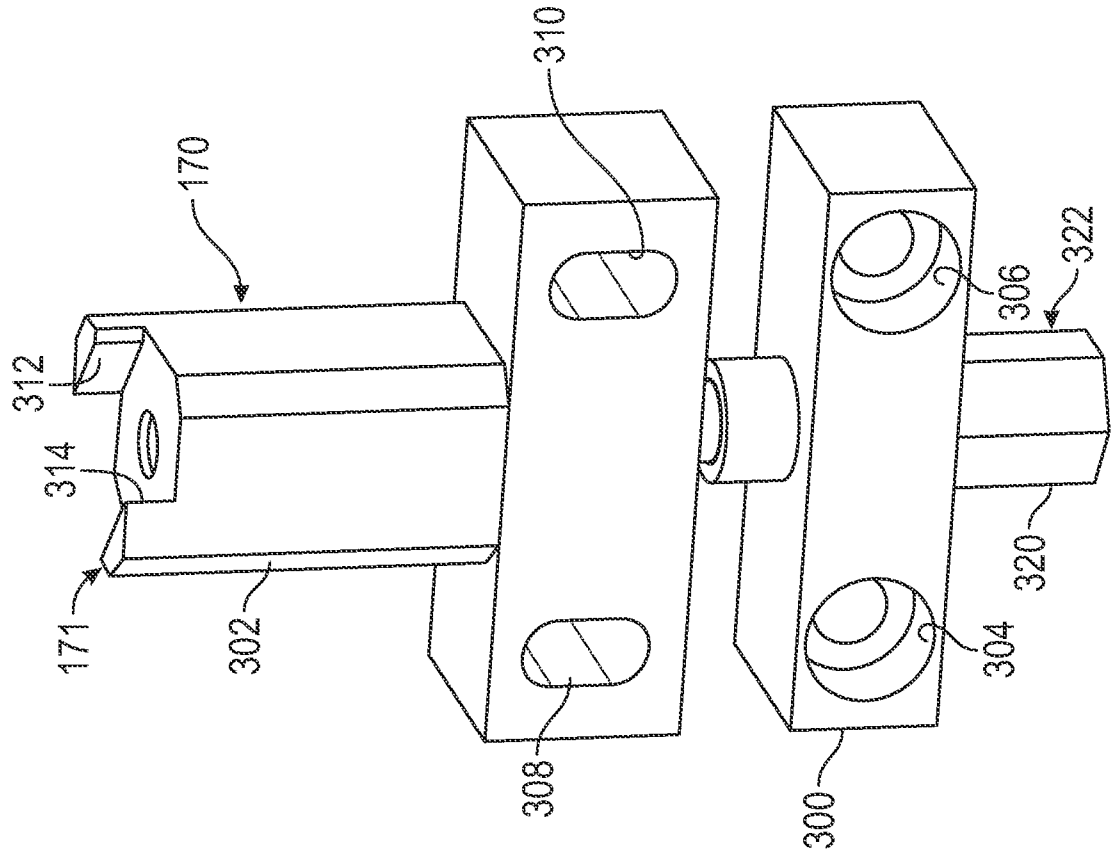
FIG. 7B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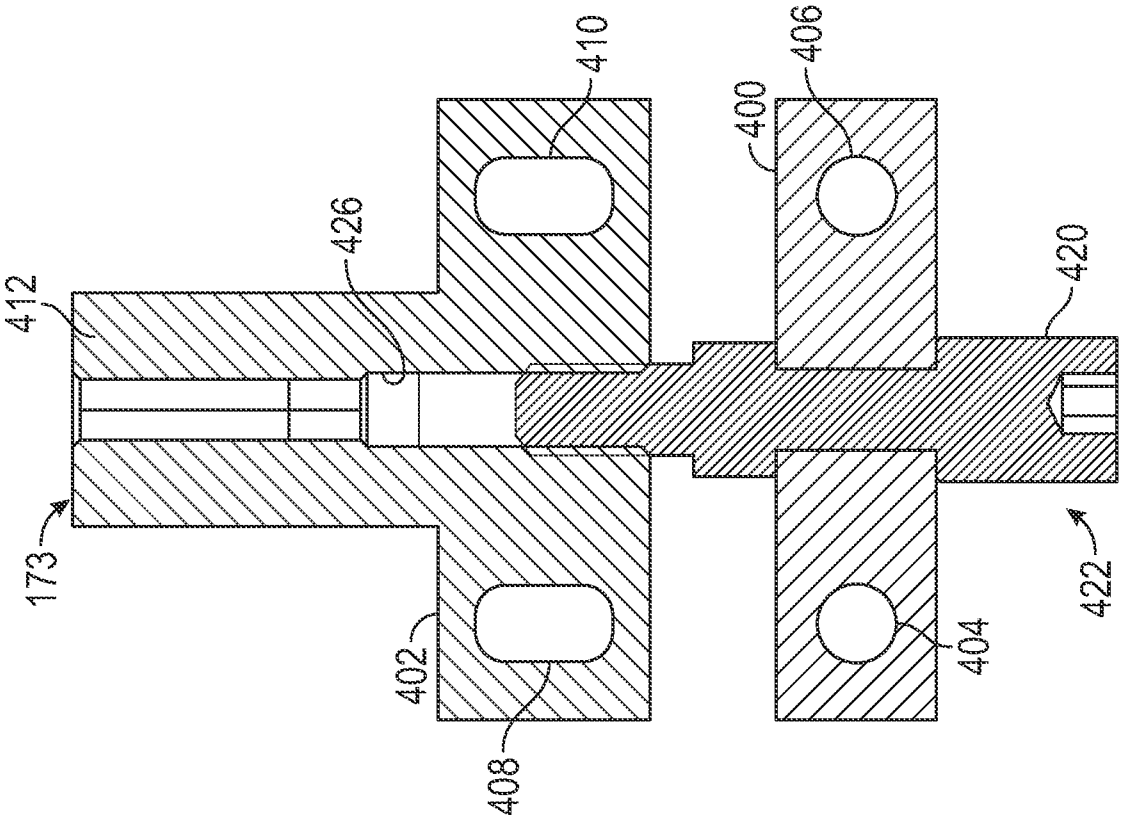
308
300

FIG. 7A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173
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404
408

FIG. 8B

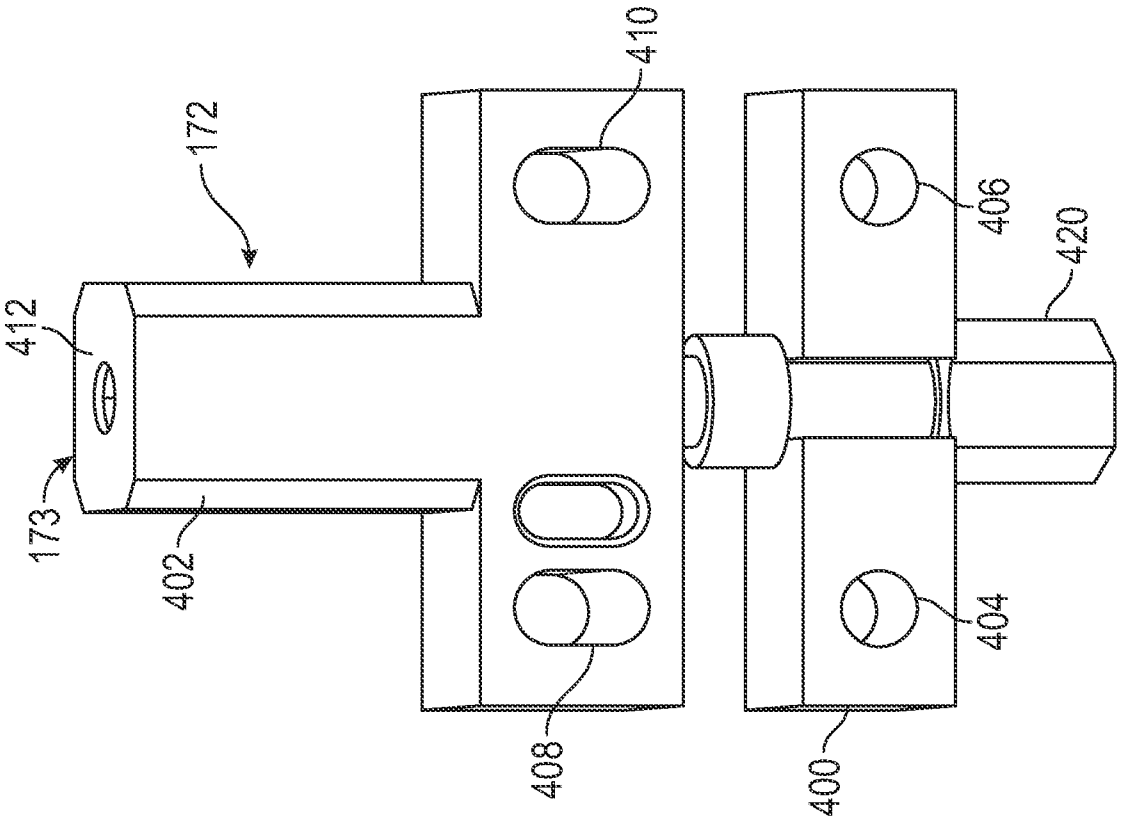
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FIG. 8A

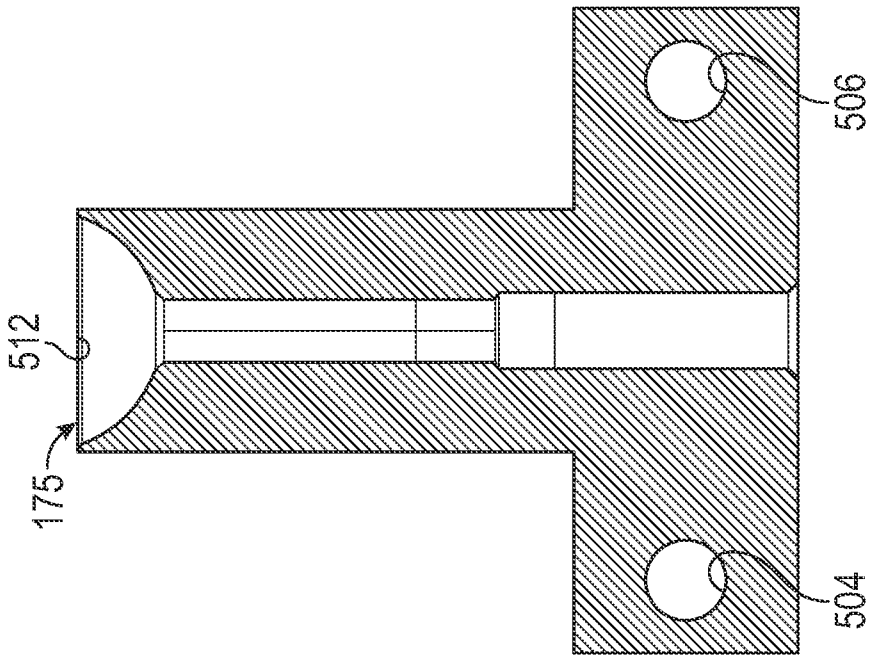

FIG. 9B

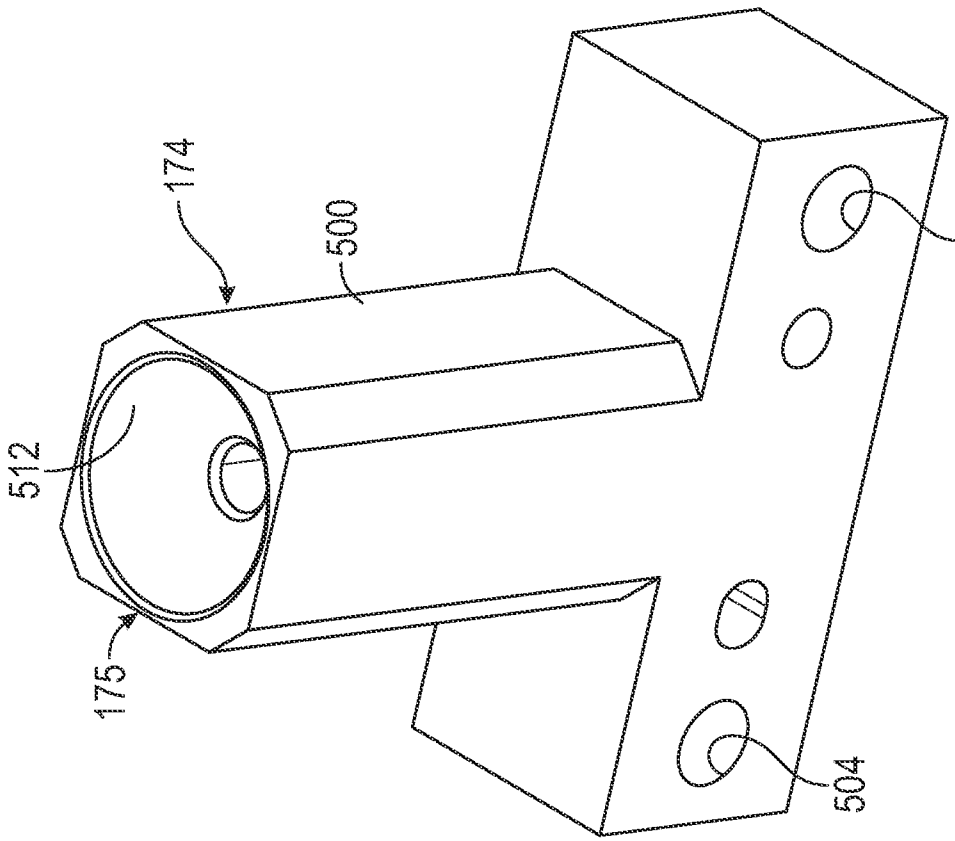

FIG. 9A

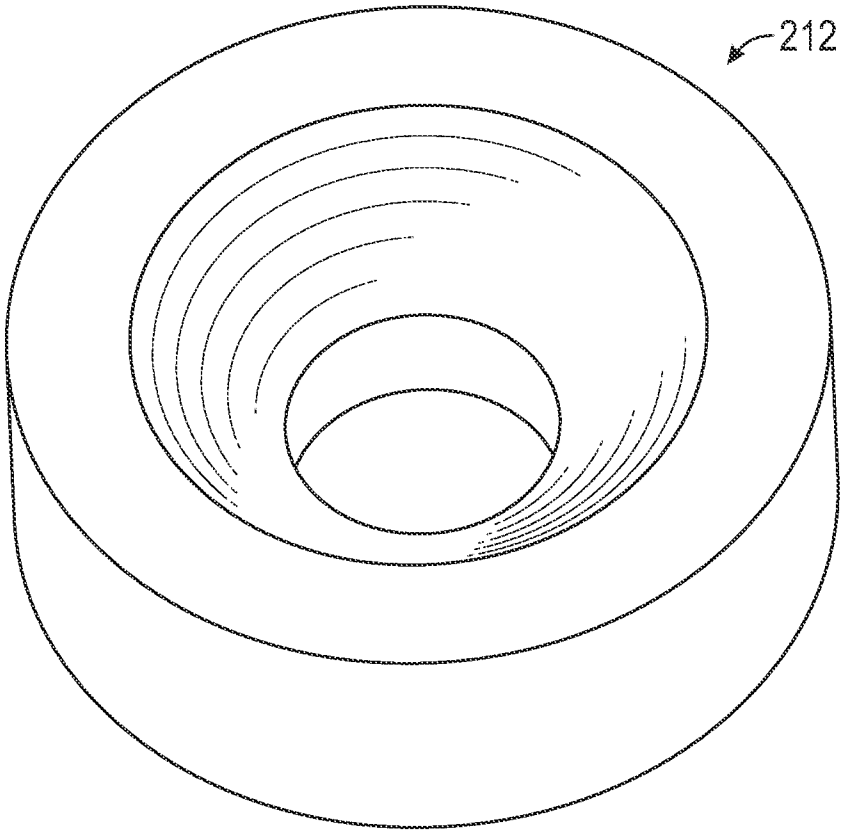

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2022/079599

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - INV. - B29C 64/245; B29C 64/118; B29C 64/194; B29C 64/25 (2023.01)
ADD. - B29C 64/209; B33Y 40/00 (2023.01)

CPC - INV. - B29C 64/245; B29C 64/194; B29C 64/209; B29C 64/118 (2023.01)

ADD. - B33Y 40/00 (2023.01)

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)
See Search History document

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

Electronic database consulted during the international search (name of database and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2019/0030806 A1 (ROBERT BOSCH TOOL CORPORATION) 31 January 2019 (31.01.2019) entire document	1-7, 12, 13, 15
Y	US 2020/0086569 A1 (MAKERBOT INDUSTRIES LLC) 19 March 2020 (19.03.2020) entire document	1-7, 12, 13, 15
A	US 2016/0214322 A1 (ORANGE MAKER LLC) 28 July 2016 (28.07.2016) entire document	1-15
A	US 2004/0204515 A1 (ROJASOVA et al) 14 October 2004 (14.10.2004) entire document	1-15
A	US 2015/0273582 A1 (STRATASYS INC.) 01 October 2015 (01.10.2015) entire document	1-15
A	US 2018/0133956 A1 (VELO3D INC.) 17 May 2018 (17.05.2018) entire document	1-15

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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"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
05 January 2023	FEB 08 2023
Name and mailing address of the ISA/ Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Authorized officer Taina Matos Telephone No. PCT Helpdesk: 571-272-4300