



(51) International Patent Classification:

B22F 10/28 (2021.01) *B29C 64/153* (2017.01)
B22F 12/20 (2021.01) *B29C 64/227* (2017.01)
B22F 12/30 (2021.01) *B29C 64/245* (2017.01)
B22F 12/33 (2021.01) *B29C 64/25* (2017.01)
B22F 12/37 (2021.01) *B33Y 10/00* (2015.01)
B22F 12/00 (2021.01) *B33Y 30/00* (2015.01)

(21) International Application Number:

PCT/US2022/011247

(22) International Filing Date:

05 January 2022 (05.01.2022)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

63/134,418 06 January 2021 (06.01.2021) US

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(54) Title: MATERIAL BED ASSEMBLY FOR A PROCESSING MACHINE

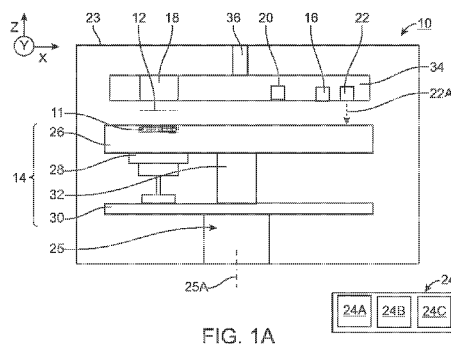


FIG. 1A

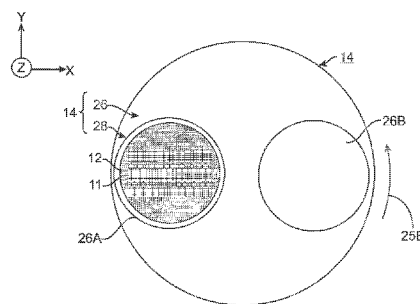


FIG. 1B

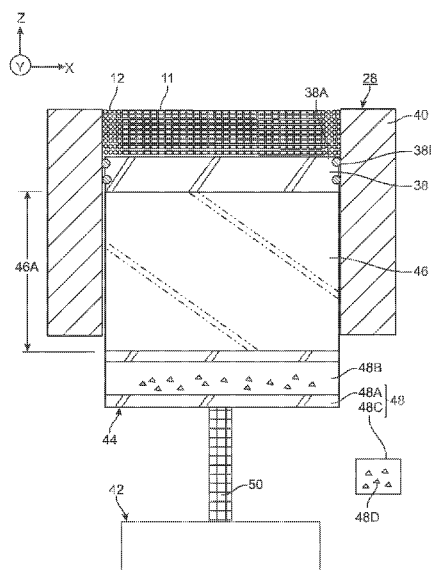


FIG. 1C

(57) **Abstract:** A processing machine (10) for building an object (11) from a material (12) includes a build platform (38), an energy system (22), a platform mover assembly (42) and a mover connector assembly (44). The build platform (38) supports the material (12). The energy system (22) directs an energy beam (22A) at the material (12) on the build platform (38) to selectively melt the material (12). The energy beam (22A) being directed at the material (12) generates heat that is transferred to the build platform (38). The platform mover assembly (42) causes relative movement between the build platform (38) and the energy system (22). The mover connector assembly (44) connects the platform mover assembly (42) to the build platform (38). The mover connector assembly (44) is configured to reduce the amount of heat transferred from the build platform (38) to the platform mover assembly (42).



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(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, IT, 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, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, 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).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*
 — *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

UNITED STATES PCT PATENT APPLICATION**of****PATRICK SHIH CHANG, JOHNATHAN AGUSTIN MARQUEZ, MICHAEL BIRK
BINNARD, SERHAD KETSAMANIAN, ALTON HUGH PHILLIPS,
MATTHEW DAVID ROSA AND LEXIAN GUO****for****MATERIAL BED ASSEMBLY FOR A PROCESSING MACHINE****RELATED APPLICATIONS**

[0001] This application claims priority on U.S. Provisional Application No: 63/134,418 filed on January 6, 2021, and entitled "MATERIAL BED ASSEMBLY FOR A PROCESSING MACHINE". As far as permitted, the contents of U.S. Provisional Application No. 63/134,418 are incorporated in their entirety herein by reference.

BACKGROUND

[0002] Three-dimensional printing systems are used to print three-dimensional objects. One type of three-dimensional printing system preheats and subsequently melts metal powder to print a three-dimensional metal part. Unfortunately, a significant amount of heat is generated during the preheating and subsequent melting of the metal powder. This significant amount of heat adversely influences the surrounding components of the three-dimensional printing system and adversely influences the resulting accuracy of the metal part.

SUMMARY

[0003] The present implementation is directed to a processing machine for building a three-dimensional object from a material. In one implementation, the processing machine

includes a build platform, an energy system, a mover assembly and a mover connector assembly. The build platform supports the material. The energy system directs an energy beam at the material on the build platform to selectively melt the material. The energy beam being directed at the material generates heat that is transferred to the build platform. The mover assembly causes relative movement between the build platform and the energy system. The mover connector assembly connects the mover assembly to the build platform. The mover connector assembly is configured to reduce the amount of heat transferred from the build platform to the mover assembly.

[0004] In another implementation, the processing machine includes (i) an energy system that directs an energy beam at the material on the build platform to selectively melt the material, wherein the energy beam directed at the material generates heat that is transferred to the build platform; a first assembly that causes a movement of the build platform; and a second assembly at least part of which is arranged opposite to the energy system with respect to the build platform, the second assembly reducing the amount of heat therethrough transferred from the build platform.

[0005] The first assembly can include a mover assembly that causes movement of the build platform at least in a direction intersecting to a support surface of the build platform that supports the material, and the second assembly includes a mover connector assembly that connects the mover assembly to the build platform. The movement of the build platform can include a movement in a direction parallel to the surface of the build platform. The first assembly can be positioned opposite to the energy system with respect to the second assembly.

[0006] As provided herein, the material is preheated and subsequently melted at relatively high temperatures by the processing machine. This will result in a significant amount of heat that is transferred to the build platform. As an overview, in certain implementations, the mover connector assembly is uniquely designed to include a thermal insulator and targeted cooling to protect sensitive components. Additionally, or alternatively, the system is uniquely designed to allow for thermal expansion without distortion. With this design, the temperature of the material and the build object on the build platform can be precisely controlled without adversely influencing other components.

[0007] In one implementation, the mover connector assembly includes a heat dissipation assembly that reduces the amount of heat transferred from the build platform to the mover assembly. Further, the processing machine can include a heat spreader that is positioned between the build platform and the mover assembly, the heat spreader being configured to increase a contact area with the heat dissipation assembly. The heat spreader can be positioned between the thermal insulator and the build platform. Alternatively, the heat spreader can be positioned between the thermal insulator and the heat dissipation assembly.

[0008] The heat dissipation assembly can include a flow channel, and a circulation system that directs a circulation fluid through the flow channel to reduce the amount of heat transferred from the build platform to the mover assembly. Alternatively, the heat dissipation assembly can include a chiller that reduces the amount of heat transferred from the build platform to the mover assembly.

[0009] The processing machine can additionally include (i) a first support frame that retains the build platform; (ii) a second mover assembly that causes relative movement between the build platform and the energy system; and (iii) a coupler assembly that couples the second mover assembly to the first support frame in a fashion that allows the first support frame to radially expand relative to second mover assembly.

[0010] Moreover, the processing machine can include a second support frame. In this design, the coupler assembly couples the first support frame to the second support frame; and the second mover assembly is coupled to the second support frame.

[0011] Further, the processing machine can include a circulation system that is configured to provide a circulation fluid for at least one of the first support frame and the second support frame.

[0012] In another implementation, the processing machine includes: (i) a build platform that supports the material; (ii) an energy system that directs an energy beam at the material on the build platform to selectively melt the material; (iii) a first support frame that retains the build platform; (iv) a mover assembly that causes relative movement between the build platform and the energy system; and (v) a coupler assembly that couples the mover assembly to the first support frame in a fashion that allows the first support frame to radially expand relative to mover assembly.

[0013] Additionally, this implementation can include one or more of the following: (i) the coupler assembly defines a kinematic coupling; (ii) a second support frame and wherein the coupler assembly couples the first support frame to the second support frame; and wherein the mover assembly is coupled to the second support frame; (iii) the coupler assembly kinematically couples the first support frame to the second support frame; and (iv) the coupler assembly includes a plurality of spaced apart flexures that couple the first support frame to the second support frame.

[0014] The mover assembly can vertically move the first support frame and the second support frame. The coupler assembly can function as a temperature buffer between the first support frame and the second support frame. The first support frame can include a build platform, and the build platform can support the material. The mover assembly can rotate the build platform respect to the first support frame.

[0015] The coupler assembly can include three v-grooves and three hemispheres. The three v-grooves can be radially arranged, and the three hemispheres can be radially arranged. Further, the three v-grooves can mate and engage with the three hemispheres. The coupler assembly can inhibit gravity sag of the first support frame.

[0016] In still another implementation, the processing machine comprises: a material bed assembly that supports the material; an energy system that directs an energy beam at the material on the material bed assembly to selectively melt the material; an environmental chamber that encloses the material bed assembly; an assembly mover assembly that selectively moves at least a portion of the material bed assembly, the assembly mover assembly being positioned outside of the environmental chamber, the assembly mover assembly including (i) a drive shaft that extends through the environmental chamber and that is connected to the material bed assembly, (ii) a connector housing that is coupled to the environmental chamber, the shaft being spaced apart from the connector housing by a bearing gap; and (iii) a bearing assembly that connects the drive shaft to the connector housing while allowing the drive shaft to move relative to the connector assembly; and a material inhibitor that inhibits material in the environmental chamber from entering the bearing gap. For example, the material inhibitor can include one or more of a baffle assembly; a wiper assembly; and/or a magnetic assembly.

[0017] In another implementation, a method for building a three-dimensional object from a material includes: supporting the material with a build platform; directing an energy beam at the material on the build platform to selectively melt the material with an energy system, wherein the energy beam directed at the material generates heat that is transferred to the build platform; moving the build platform with a first assembly; and reducing the amount of heat transferred from the build platform through the first assembly with a second assembly, the second assembly at least partly being arranged opposite to the energy system with respect to the build platform.

[0018] In still another implementation, a method for building a three-dimensional object from a material includes: supporting the material with a first support frame; directing an energy beam at the material to selectively melt the material with an energy system; causing relative movement between the first support frame and the energy system with a mover assembly; and coupling the mover assembly to the first support frame in a fashion that allows the first support frame to thermally expand with a coupler assembly.

[0019] In yet another implementation, a method for building a three-dimensional object from a material includes: supporting the material with a material bed assembly; directing an energy beam at the material on the material bed assembly to selectively melt the material with an energy system; enclosing the material bed assembly with an environmental chamber; selectively moving at least a portion of the material bed assembly with an assembly mover assembly, the assembly mover assembly being positioned outside of the environmental chamber, the assembly mover assembly including a drive shaft that extends through the environmental chamber and that is connected to the material bed assembly; and sealing the shaft to the environmental chamber with a fluid bearing, the fluid bearing allowing the shaft to mover relative to the environmental chamber.

[0020] In another implementation, a method for building a three-dimensional object from a material includes: supporting the material with a material bed assembly; directing an energy beam at the material on the material bed assembly to selectively melt the material with an energy system; enclosing the material bed assembly with an environmental chamber; selectively moving at least a portion of the material bed assembly with an assembly mover assembly, the assembly mover assembly being

positioned outside of the environmental chamber, the assembly mover assembly including (i) a drive shaft that extends through the environmental chamber and that is connected to the material bed assembly, (ii) a connector housing that is coupled to the environmental chamber, the shaft being spaced apart from the connector housing by a bearing gap; and (iii) a bearing assembly that connects the drive shaft to the connector housing while allowing the drive shaft to move relative to the connector housing; and inhibiting material in the environmental chamber from entering the bearing gap with a material inhibitor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] The novel features of this embodiment, as well as the embodiment itself, both as to its structure and its operation, will be best understood from the accompanying drawings, taken in conjunction with the accompanying description, in which similar reference characters refer to similar parts, and in which:

[0022] Figure 1A is a simplified side illustration of an implementation of a processing machine having features of the present embodiment;

[0023] Figure 1B is a simplified top illustration of a material bed assembly from Figure 1A;

[0024] Figure 1C is a simplified cut-away view of a portion of the material bed assembly of Figure 1A and an object;

[0025] Figure 2 is a simplified cut-away view of a portion of another implementation of the material bed assembly, and the object;

[0026] Figure 3 is a simplified cut-away view of a portion of still another implementation of the material bed assembly, and the object;

[0027] Figure 4A is a simplified perspective view of another implementation of the material bed assembly, and the object;

[0028] Figure 4B is a simplified cut-away view of the material bed assembly and the object of Figure 4A;

[0029] Figure 4C is a simplified perspective view of one implementation of a frame coupler assembly from Figure 4A;

[0030] Figure 5 is a simplified side view of a portion of still another implementation of the material bed assembly, and the object;

[0031] Figure 6 is a simplified cut-away view of yet another implementation of the material bed assembly, and the object;

[0032] Figure 7 is a simplified cut-away view of another implementation of the material bed assembly;

[0033] Figure 8 is a simplified cut-away view of still another implementation of the material bed assembly;

[0034] Figure 9A is a simplified cut-away view of yet another implementation of the processing machine;

[0035] Figure 9B is an enlarged view of a portion of the processing machine of Figure 9A; and

[0036] Figure 9C is an enlarged view of the portion of the processing machine of Figure 9B;

[0037] Figure 10 is a simplified view of a portion of still another implementation of the processing machine;

[0038] Figure 11 is a simplified of a portion of yet another implementation of the processing machine;

[0039] Figure 12 is a simplified view of a portion of another implementation of the processing machine; and

[0040] Figure 13 is a simplified view of a portion of still another implementation of the processing machine.

DESCRIPTION

[0041] Figure 1A is a simplified schematic side illustration of a processing machine 10 that may be used to manufacture one or more three-dimensional object(s) 11 (only one object 11 is illustrated in phantom). As provided herein, the processing machine 10 can be an additive manufacturing system, e.g., a three-dimensional printer, in which a portion of a material 12 (illustrated as small circles) is sequentially joined, melted, solidified, and/or fused together in a series of material layers to manufacture one or more three-dimensional object(s) 11. In Figure 1A, the object(s) 11 include a plurality of small

squares that represent the joining of the material 12 to form the object 11.

[0042] The type of three-dimensional object(s) 11 manufactured with the processing machine 10 may be almost any shape or geometry. As a non-exclusive example, the three-dimensional object 11 may be a metal part, or another type of part, for example, a resin (plastic) part or a ceramic part, etc. The three-dimensional object 11 may also be referred to as a “built part”. It should be noted with the present design, one or more objects 11 can be simultaneously made with the processing machine 10.

[0043] The type of material 12 joined and/or fused together may be varied to suit the desired properties of the object(s) 11. As a non-exclusive example, the material 12 may include metal powder particles (e.g., including one or more of titanium, aluminum, vanadium, chromium, copper, stainless steel, or other suitable metals) or alloys for metal three-dimensional printing. Alternatively, the material 12 may be non-metal material, a plastic, polymer, glass, ceramic material, organic material, an inorganic material, or any other material known to people skilled in the art. The material 12 may also be referred to as “powder” or “powder particles”.

[0044] Particle sizes of the material 12 can be varied. In one implementation, a common particle size is approximately fifty microns. Alternatively, in other non-exclusive examples, the particle size can be approximately twenty, thirty, forty, sixty, seventy, eighty, ninety, or one hundred microns.

[0045] A number of different designs of the processing machine 10 are provided herein. In certain implementations, the processing machine 10 includes (i) a material bed assembly 14; (ii) a pre-heat device 16 (illustrated as a box); (iii) a material supply assembly 18 (illustrated as a box); (iii) a measurement device 20 (illustrated as a box); (iv) an energy system 22 (illustrated as a box); (v) a control system 24 (illustrated as a box); and (vi) an assembly mover assembly 25 (also sometimes referred to simply as a “mover assembly”) that causes relative motion between the material bed assembly 14 and the material supply assembly 18. The design of each of these components may be varied pursuant to the teachings provided herein. Further, the positions of the components of the processing machine 10 may be different than that illustrated in Figure 1A. Moreover, the processing machine 10 may include a post-heat device which heats the material and/or the build parts.

[0046] Moreover, the processing machine 10 can include more components or fewer components than illustrated in Figure 1A. For example, the processing machine 10 can include a cooling device (not shown in Figure 1A) that uses radiation, conduction, and/or convection to cool the material 12. Further, the processing machine 10 can include multiple, spaced apart, material supply assemblies 18. Additionally, or alternatively, for example, the processing machine 10 can be designed without the pre-heat device 16 and/or the measurement device 20.

[0047] As discussed above, the material 12 is preheated and subsequently melted at relatively high temperatures. This will result in a significant amount of heat that is transferred to the material bed assembly 14. As an overview, in certain implementations, the material bed assembly 14 is uniquely designed to include a thermal insulator and targeted cooling to protect sensitive components. Additionally, or alternatively, the material bed assembly 14 is uniquely designed to allow for thermal expansion without distortion. With this design, the temperature of the material 12 and the build object 11 on the material bed assembly 14 can be precisely controlled without adversely influencing the material bed assembly 14. As a result thereof, the built object 11 will be more accurate.

[0048] A number of Figures include an orientation system that illustrates an X axis, a Y axis that is orthogonal to the X axis, and a Z axis that is orthogonal to the X and Y axes. It should be noted that any of these axes can also be referred to as the first, second, and/or third axes. Further, as used herein, movement with six degrees of freedom shall mean along and about the X, Y, and Z axes.

[0049] It should be noted that the processing machine 10 may be operated in a controlled environment, e.g., such as a vacuum, using an environmental chamber 23 (illustrated in Figure 1A as a box) that encircles the build area. For example, one or more of the components of the processing machine 10 can be positioned entirely or partly within the environmental chamber 23. Alternatively, at least a portion of one or more of the components of the processing machine 10 may be positioned outside the environmental chamber 23. Still alternatively, the processing machine 10 may be operated in a non-vacuum environment such as an inert gas (e.g., nitrogen gas or argon gas) environment or non-inert gas (e.g. hydrogen) environment. The pressure of such gas may be below

atmospheric pressure.

[0050] The material bed assembly 14 supports the material 12 while the object(s) 11 is being built. In the non-exclusive implementation of Figure 1A, the material bed assembly 14 includes (i) a first support frame 26, (ii) one or more build platform assemblies 28 (only one is illustrated in Figure 1A) that supports the material 12 and the object 11 while being formed; (iii) a second support frame 30; and (iv) a frame coupler assembly 32 that physically couples the first support frame 26 to the second support frame 32. The design of each of these components can be varied pursuant to the teachings provided herein.

[0051] Figure 1B is a simplified top view of the material bed assembly 14 of Figure 1A with the partly built object 11 (illustrated with small squares) and the top layer of powder 12 (illustrated with small circles). With reference to Figures 1A and 1B, the first support frame 26 is rigid and supports the build platform assembly 28. In one, non-exclusive implementation, the first support frame 26 is generally circular disk-shaped and includes a circular-shaped frame aperture 26A for receiving the build platform assembly 28. Alternatively, for example, the first support frame 26 can be octagon-shaped, rectangular-shaped, or have yet a different configuration. Asymmetric shapes are also possible, and in certain implementations, the center of gravity is at the center of the rotation.

[0052] Additionally, the first support frame 26 can include one or more frame counterweights 26B to balance the center of mass of the first support frame 26.

[0053] Each build platform assembly 28 supports the material 12 and the object 11 while being formed. Figures 1A and 1B illustrates a single build platform assembly 28. Alternatively, the material bed assembly 14 can be designed to include multiple build platform assemblies 28. A number of different build platform assemblies 28 are described in more detail below.

[0054] The second support frame 30 is rigid, is positioned below the first support frame 26, and supports the first support frame 26 and/or each build platform assembly 28. In one non-exclusive implementation, the second support frame 30 is generally circular disk-shaped. Alternatively, for example, the second support frame 30 can be octagon-shaped, rectangular-shaped, or have yet a different configuration. The shape of the second support frame 30 does not need to match the shape of the first support frame 26.

[0055] It should be noted that the first support frame 26 is positioned above the second support frame 30. Thus, the first support frame 26 can also be referred to as an upper support frame, while the second support frame 30 can be referred to as a lower support frame. Further, the support frames 26, 30 can each also be referred to as a turntable.

[0056] The frame coupler assembly 32 physically couples the first support frame 26 to the second support frame 30 and maintains the support frames 26, 30 spaced apart. In certain implementations, the platform coupler assembly 32 maintains a precise alignment between the support frames 26, 30, while allowing for relative thermal expansion between the support frames 26, 30. Further, in certain implementations, the platform coupler assembly 32 inhibits heat transfer between the support frames 26, 30. Suitable platform coupler assemblies 32 are described in more detail below.

[0057] The pre-heat device 16 selectively preheats the material 12 on the material bed assembly 14. The number of the pre-heat devices 16 may be one or plural. The design of the pre-heat device 16 and the desired preheated temperature may be varied. In one embodiment, the pre-heat device 16 may include one or more pre-heat energy source(s) that direct one or more pre-heat beam(s) (not shown) at the material 12. Each pre-heat beam may be steered as necessary. As alternative, non-exclusives examples, each pre-heat device 16 may be an electron beam system, a mercury lamp, an infrared laser, a laser that generates light outside of the infrared range, a supply of heated air, a thermal radiation system, a visual wavelength optical system, or a microwave optical system. The desired preheated temperature may be 50%, 75%, 90%, or 95% of the melting temperature of the material 12 used in the printing. It is understood that different materials have different melting points and therefore different desired pre-heating points. As non-exclusive examples, the desired preheated temperature may be at least 300, 500, 700, 900, or 1000 degrees Celsius. Energy input may also vary dependent on melt duty of previous layers, specific regions on a layer, or progress though the build. A detailed discussion of suitable pre-heat devices is contained in PCT Application No: PCT/US2020/62490, entitled "ADDITIVE MANUFACTURING SYSTEM WITH THERMAL CONTROL OF MATERIAL" filed on November 27, 2020. As far as permitted, the contents of PCT Application No: PCT/US2020/62490 is incorporated in its entirety herein by reference.

[0058] As discussed above, when the material 12 is preheated on the build platform assembly 28, a significant amount of heat is transferred to the build platform 28 and other components of the material bed assembly 14.

[0059] The material supply assembly 18 deposits the material 12 onto the build platform assembly 28. The number of the material supply assemblies 18 may be one or plural. With the present design, the material supply assembly 18 accurately deposits the material 12 onto the build platform assembly 28, to sequentially form each material layer. Once a portion of the upper material layer has been melted with the energy system 22, the material supply assembly 18 can be controlled to accurately deposit another (subsequent) material layer. With this design, the three-dimensional object 11 is formed through consecutive fusions of consecutively formed cross-sections of material 12 in one or more material layers.

[0060] In the non-exclusive implementation of Figure 1A, the material supply assembly 18 is an overhead system that supplies the material 12 via gravity onto the top of the material bed assembly 14. Alternatively, the material supply assembly 18 can be at a different location and/or can supply the material 12 onto the top of the material bed assembly 14 in a different manner. More details of a non-exclusive, suitable material supply assembly is disclosed in the PCT Application No. PCT/US2020/040498. As far as permitted, the contents of PCT Application No. PCT/US2020/040498 is incorporated in its entirety herein by reference.

[0061] The measurement device 20 inspects and monitors the melted (fused) layers of the object 11 as the object 11 is being built, and/or the deposition of the material 12. The number of the measurement devices 20 may be one or plural. For example, the measurement device 20 can measure both before and after the material 12 is distributed. As non-exclusive examples, the measurement device 20 may include one or more optical elements such as a uniform illumination device, fringe illumination device (structured illumination device), cameras that function at one or more wavelengths, lens, interferometer, or photodetector, or a non-optical measurement device such as an ultrasonic, eddy current, or capacitive sensor.

[0062] The energy system 22 selectively heats and melts the material 12 to sequentially form each of the layers of the object 11. The energy system 22 can

selectively melt the material 12 at least based on a data regarding to the object 11 to be built. The data may be corresponding to a computer-aided design (CAD) model data. The number of the energy systems 22 may be one or plural. The design of the energy system 22 can be varied. In one embodiment, the energy system 22 can direct one or more irradiation (energy) beam(s) 22A at the material 12. The one or more energy systems 22 can be controlled to steer the energy beam(s) 22A to melt the material 12.

[0063] As alternative, non-exclusives examples, the energy system 22 can be designed to include one or more of the following: (i) an electron beam generator that generates a charged particle electron beam; (ii) an irradiation system that generates an irradiation beam; (iii) an infrared laser that generates an infrared beam; (iv) a laser that generates light outside the infrared range, (v) a mercury lamp; (vi) a thermal radiation system; (vii) a visual wavelength system; (viii) a microwave wavelength system; or (ix) an ion beam system.

[0064] Different materials 12 have different melting points. As non-exclusive examples, the desired melting temperature may be at least 1000, 1400, 1700, 2000, or more degrees Celsius. When the material 12 is melted on the build platform assembly 28, a significant amount of heat is transferred to the build platform 28 and other components of the material bed assembly 14. It should be noted that the built object 11 may or may not be fused to the build platform 28 and the build platform 28 can be consumable.

[0065] The control system 24 controls the components of the processing machine 10 to build the three-dimensional object 11 from the computer-aided design (CAD) model by successively melting portions of one or more of the material layers. For example, the control system 24 can control (i) the material bed assembly 14; (ii) the pre-heat device 16; (iii) the material supply assembly 18; (iii) the measurement device 20; (iv) the energy system 22; and/or (v) the assembly mover assembly 25. The control system 24 can be a centralized or a distributed system.

[0066] The control system 24 may include, for example, a CPU (Central Processing Unit) 24A, a GPU (Graphics Processing Unit) 24B, and electronic memory 24C. The control system 24 functions as a device that controls the operation of the processing machine 10 by the CPU executing the computer program. This computer program is a

computer program for causing the control system 24 (for example, a CPU) to perform an operation to be described later to be performed by the control system 24 (that is, to execute it). That is, this computer program is a computer program for making the control system 24 function so that the processing machine 10 will perform the operation to be described later. A computer program executed by the CPU may be recorded in a memory (that is, a recording medium) included in the control system 24, or an arbitrary storage medium built in the control system 24 or externally attachable to the control system 24, for example, a hard disk or a semiconductor memory. Alternatively, the CPU may download a computer program to be executed from a device external to the control system 24 via the network interface. Further, the control system 24 may not be disposed inside the processing machine 10, and may be arranged as a server or the like outside the processing machine 10, for example. In this case, the control system 24 and the processing machine 10 may be connected via a communication line such as a wired communications line (cable communications), a wireless communications line, or a network. In case of physically connecting with a wired communications line, it is possible to use serial connection or parallel connection of IEEE1394, RS-232x, RS-422, RS-423, RS-485, USB, etc. or 10BASE-T, 100BASE-TX, 1000BASE-T or the like via a network. Further, when connecting using radio, radio waves such as IEEE 802.1x, OFDM, or the like, radio waves such as Bluetooth (registered trademark), infrared rays, optical communication, and the like may be used. In this case, the control system 24 and the processing machine 10 may be configured to be able to transmit and receive various types of information via a communication line or a network. Further, the control system 24 may be capable of transmitting information such as commands and control parameters to the processing machine 10 via the communication line and the network. The processing machine 10 may include a receiving device (receiver) that receives information such as commands and control parameters from the control system 24 via the communication line or the network. As a recording medium for recording the computer program executed by the CPU, a CD-ROM, a CD-R, a CD-RW, a flexible disk, an MO, a DVD-ROM, a DVD-RAM, a DVD-R, a DVD + R, a DVD-RW, a magnetic medium such as a magnetic disk and a magnetic tape such as DVD + RW and Blu-ray (registered trademark), a semiconductor memory such as an optical disk, a magneto-optical disk, a

USB memory, or the like, and a medium capable of storing other programs. In addition to the program stored in the recording medium and distributed, the program includes a form distributed by downloading through a network line such as the Internet. Further, the recording medium includes a device capable of recording a program, for example, a general-purpose or dedicated device mounted in a state in which the program can be executed in the form of software, firmware or the like. Furthermore, each processing and function included in the program may be executed by program software that can be executed by a computer, or processing of each part may be executed by hardware such as a predetermined gate array (FPGA, ASIC) or program software, and a partial hardware module that realizes a part of hardware elements may be implemented in a mixed form.

[0067] The assembly mover assembly 25 is controlled to cause relative motion between (i) the material bed assembly 14, and (ii) the pre-heat device 16, the material supply assembly 18, the measurement device 20, and the energy system 22. The design of the assembly mover assembly 25 can be varied to achieve the movement requirements of the processing machine 10. In one implementation, the assembly mover assembly 25 rotates the material bed assembly 14 about a rotational axis 25A (e.g., parallel to the Z axis) in a first rotational direction 25B (e.g., counter clockwise) relative to the material supply assembly 18, the pre-heat device 16, the measurement device 20, and the energy system 22. The assembly mover assembly 25 can move the support frame 26 at a substantially constant or variable angular velocity about the rotational axis 25A. In one implementation, the assembly mover assembly 25 causes movement of the build platform assembly 28 at least in a direction intersecting to a support surface 38A (illustrated in Figure 1C) that supports the material 12.

[0068] Alternatively, or additionally, the assembly mover assembly 25 can be designed to move the material bed assembly 14 linearly, e.g., along the X axis and/or along the Y axis, relative to the pre-heat device 16, the material supply assembly 18, the measurement device 20, and the energy system 22. Still alternatively, or additionally, the assembly mover assembly 25 can be designed to move the material supply assembly 18 (e.g., rotate and/or move linearly) relative to the material bed assembly 14. The assembly mover assembly 25 can include one or more actuators (e.g., linear or rotary actuators), and/or electromagnetic motors. Further, the assembly mover assembly 25 can include

one or more pulleys, belts, gears, shafts or other connecting components.

[0069] Additionally, the processing machine 10 can include a component housing 34 that retains the pre-heat device 16, the material supply assembly 18, the measurement device 20, and the energy system 22. Collectively these components may be referred to as a top assembly. Further, the processing machine 10 can include a housing mover 36 that can be controlled to selectively move the top assembly relative to the material bed assembly 14. The housing mover 36 can include one or more actuators (e.g., linear or rotary actuators) that move the top assembly linearly and/or rotationally.

[0070] Still alternatively, one or more of the pre-heat device 16, the material supply assembly 18, the measurement device 20, and the energy system 22 can be moved relative to the component housing 34 and the material bed assembly 14.

[0071] Figure 1C is a simplified cut-away view of the build platform assembly 28 of Figures 1A and 1B supporting the material 12 and the object 11 while the object 11 is being built. In this non-exclusive implementation, the build platform assembly 28 includes a build platform 38, a sidewall 40, a platform mover assembly 42 (also sometimes referred to simply as a “mover assembly”), and a mover connector assembly 44 that connects the platform mover assembly 42 to the build platform 38. The design of each of these components can be varied.

[0072] In one implementation, (i) the build platform 38 is generally rigid, disk-shaped; (ii) the sidewall 40 is rigid, generally tubular-shaped; and (iii) the platform mover assembly 42 moves the build platform 38 linearly relative to the sidewall 40. With this design, the build platform 38 is positioned within the sidewall 40, and the build platform 38 can be selectively moved, i.e., vertically lowered, like an elevator within and/or relative to the sidewall 40 with the platform mover assembly 42 during the manufacturing process. Fabrication can begin with the build platform 38 placed near the top of the sidewall 40. The material supply assembly 18 (illustrated in Figure 1A) deposits the thin layer of material 12 onto the build platform 38 as it is moved below the material supply assembly 18. At an appropriate time, the build platform 38 is stepped down one layer thickness with the platform mover assembly 42 so the next layer of material 12 may be distributed properly. Alternatively, the build platform 38 can be moved in steps that are smaller than the material layer or moved in a continuous fashion, rather than in discrete steps.

[0073] In this design, the build platform 38 defines a circular-shaped build area (or support surface) 38A that receives the material 12. Alternatively, for example, the build platform 38 can have a different configuration, e.g., rectangular or polygonal-shaped. In these alternative designs, the sidewall 40 will have a complementary shape.

[0074] As non-exclusive examples, suitable material for the build platform 38 and the sidewall 40 can include stainless steel, molybdenum, titanium, tungsten, or ceramic materials. In certain embodiments, the build platform 38 is made of the same material as the built object 11. The sidewall 40 can be made of a material having a low thermal conductivity to inhibit the transfer of heat to the surrounding components. Alternatively, the sidewall 40 can be made of a material having a high thermal conductivity so it can remove excess heat from the object 11 and radiate the heat laterally outwards to the surrounding environment. The side wall 40 does not have to be made of a single material. For example, it may be made of a material having different thermal conductivity between the upper part and the lower part of the side wall 40. The thermal conductivity of the material forming the upper part of the side wall 40 may be higher than the thermal conductivity of the material forming the lower part of the side wall 40. Alternatively, the thermal conductivity of the material forming the upper part of the side wall 40 may be lower than the thermal conductivity of the material forming the lower part of the side wall 40.

[0075] Additionally, and optionally, the build platform 38 can include one or more seals 38B (two are shown) that seal the build platform 38 to the sidewall 40, while allowing for relative motion between the build platform 38 and the sidewall 40. Also, the build platform 38 can be designed without seals. In this design, the material 12 can flow through and a natural bridge phenomenon can inhibit the material 12 from over-leaking.

[0076] In Figure 1C, the platform mover assembly 42 selectively moves the build platform 38 relative to the sidewall 40. In one implementation, the platform mover assembly 42 includes one or more linear actuators that move the build platform 38 relative to the sidewall 40. Additionally, or alternatively, the platform mover assembly 42 can include one or more rotary actuators that selectively rotate the build platform 38 relative to the sidewall 40.

[0077] It is appreciated that in various implementations, movement of the build

platform 38 relative to the sidewall 40 with the platform mover assembly 42 also causes relative movement between the build platform 38 and the top assembly, i.e. the pre-heat device 16 (illustrated in Figure 1A), the material supply assembly 18 (illustrated in Figure 1A), the measurement device 20 (illustrated in Figure 1A), and the energy system 22 (illustrated in Figure 1A).

[0078] The mover connector assembly 44 fixedly connects the platform mover assembly 42 to the build platform 38. Further, in certain implementations, the mover connector assembly 44 is uniquely designed to reduce heat generated during the preheating and/or melting of the material 12 on the build platform 28 from being transferred to the platform mover assembly 42. In one, non-exclusive implementation, the mover connector assembly 44 includes a thermal insulator 46, a heat dissipation assembly 48, and a connector rod 50. Alternatively, for example, the mover connector assembly 44 could be designed without one or more of the thermal insulator 46, the heat dissipation assembly 48, and the connector rod 50.

[0079] In certain, non-exclusive implementations, the thermal insulator 46 (i) is rigid; (ii) physically couples the build platform 38 to the heat dissipation assembly 48; and (iii) partly thermally decouples the heat dissipation assembly 48 from the build platform 38. In certain implementations, the thermal insulator 46 thermally isolates the heat dissipation assembly 48 from the build platform 38, and reduces the amount of heat transferred from the build platform 38 to the heat dissipation assembly 48. As a result of this thermal isolation, it is easier to maintain the desired temperature of the material 12 and the object 11 on the build platform 38. This allows for a more accurately built object 11.

[0080] Further, because of this thermal isolation, less heat has to be removed by the heat dissipation assembly 48, and/or the platform mover assembly 42 is subjected to less heat that can adversely influence the performance of the platform mover assembly 42.

[0081] The design of the thermal insulator 46 can be varied. In the non-exclusive implementation of Figure 1C, the thermal insulator 46 is a cylindrical-shaped block that is fixedly attached to the bottom of the build platform 38. Additionally, the thermal insulator 46 is sized to be selectively movable with the build platform 38 within the sidewall 40. Further, the thermal insulator 46 is made of a material having a relatively low thermal conductivity. As alternative, non-exclusive examples, as used herein, relatively low

thermal conductivity shall mean less than 0.5, 1, 2, 5, 7 or 10 Watts per meter-Kelvin. A non-exclusive list of suitable materials or alloys for the thermal insulator 46 includes, but is not limited to, zirconia, glass, fiberglass, Yttria, Forsterite, Cordierite, Steatite, aerogel, refractory insulation, calcium carbonate, silicon nitride, alumina, an open cell ceramic foam, or an open cell metallic foam.

[0082] It should be noted that the amount of thermal isolation provided by the thermal insulator 46 can be adjusted by changing one or more of the following: (i) the material utilized for the thermal insulator 46; (ii) the cross-sectional area of the thermal insulator 46; and/or (iii) a height 46A of the thermal insulator 46. Generally, the thermal isolation increases by (i) decreasing the thermal conductivity of the material utilized for the thermal insulator 46; (ii) decreasing the cross-sectional area of the thermal insulator 46 (or localized necking); and/or (iii) increasing the height 46A of the thermal insulator 46. The amount of thermal isolation may change depending on the amount of heat transferred to the material 12 on the build platform 38. For example, the amount of thermal isolation may change depending on at least the irradiation time of the energy from the energy system 22, the pre-heat device 16, or the post-heat device. Further, the amount of thermal isolation may change depending on the z-position of the build platform 38.

[0083] The heat dissipation assembly 48 dissipates (removes heat) received from the thermal insulator 46 to maintain the platform mover assembly 42 at a desired (i.e., sufficiently low) temperature. The design of the heat dissipation assembly 48 can be varied. In the non-exclusive implementation of Figure 1C, the heat dissipation assembly 48 includes (i) a heat exchanger 48A that defines a flow channel 48B; and (ii) a circulation system 48C (illustrated with a box) that circulates a circulation fluid 48D (illustrated with small triangles) through the flow channel 48B to control the temperature of the heat exchanger 48A. In this design, the heat exchanger 48A is rigid and is secured to the bottom of the thermal insulator 46. Moreover, the heat exchanger 48A can be lined with copper or another material with relatively high thermal conductivity. Further, the circulation system 48C includes one or more pumps, reservoirs, chillers, etc., to control the flow rate and/or temperature of the circulation fluid 48D that is directed through the heat exchanger 48A to remove the heat that is transferred from the thermal insulator 46. The heat removal amount may change depending on the amount of heat transferred to

the material 12 on the build platform 38. For example, the heat removal amount may change depending on at least the irradiation time of the energy from the energy system 22, the pre-heat device 16, or the post-heat device. Further, the heat removal amount may change depending on the z-position of the build platform 38.

[0084] Alternatively, for example, the heat dissipation assembly 48 can include another type of chiller, such as a refrigeration system, or an external heat exchanger. The circulation fluid 48D can also be re-routed to other parts of the system that require stable heating.

[0085] The connector rod 50 connects the heat dissipation assembly 48 to the platform mover assembly 42. In Figure 1C, the connector rod 50 is cylindrical, generally rigid beam-shaped. However, the connector rod 50 can have a different configuration than is illustrated in Figure 1C.

[0086] With the present design, the problem of maintaining a consistent high temperature of the material 12 and the object 11 on the build platform 38 while also maintaining a consistent low temperature to avoid damage of the platform mover assembly 42 is solved by using a combination of the high temperature thermal insulator 46 and targeted cooling with the heat dissipation assembly 48. In other words, the heat dissipation assembly 48 controls the temperature of the platform mover assembly 42 while the thermal insulator allows a large temperature difference between the heat dissipation assembly 48 and the build platform 38.

[0087] With reference to Figures 1A-1C, in a specific example, utilizing a charged particle beam such as an electron beam as the melting beam 22A, if the material 12 is a metal powder (usually stainless steel or titanium), the material 12 should be sintered with the pre-heat device 16 to a near-melt temperature (between 900C and 1000C) in order to reduce particle “smoking” during the melting process, and to reduce the amount of energy needed by the melting beam 22A. In addition, the temperature of the metal material 12 must be maintained at an elevated temperature even after it is sintered and partially melted to form the built object 11 to prevent thermal shrinkage and stress. As a result, this high temperature must be maintained in the material 12 for the duration of the build, which can last several hours.

[0088] Further, because the material 12 is added after every build layer, the material

12 is constantly being added to the build platform 38. This material 12 comes in “cold” and must also be warmed to the pre-heat temperature by the pre-heat device 16 and/or by residual heat in the sintered material 12 and built part 11. Heat is also being added via the melting beam 22A and any additional heaters (not shown) positioned around the material bed assembly 14. Simultaneously, heat is also removed via radiation and conduction to the surrounding environment (convection can be small if the environment is a vacuum). Therefore, the temperature of the material 12 on the build platform 38 is in constant flux where relatively cold material 12 is being added to the system and heat is both added to and removed from the system. For example, this constant flux makes maintaining a high pre-heat temperature (e.g., one thousand degrees Celsius) of the material 12 a challenge.

[0089] The present design can be used to control and maintain the desired temperature of the material 12 on the build platform 38 by insulating the build platform 38 with the thermal insulator 46, and protecting the platform mover assembly 42 with the heat dissipation assembly 48. This will reduce the energy output of the melting beam 22A and minimize thermal shrinkage in the built object 11.

[0090] Figure 2 is a simplified cut-away view of the object 211, and a portion of another implementation of the material bed assembly 214 that can be utilized in the processing machine 10 of Figure 1A, or another type of three-dimensional processing machine. In particular, Figure 2 is a simplified cut-away view of another implementation of the build platform assembly 228 supporting the material 212 and the object 211 while the object 211 is being built. In this non-exclusive implementation, the build platform assembly 228 includes a build platform 238, a sidewall 240, a platform mover assembly 242, and a mover connector assembly 244 that connects the platform mover assembly 242 to the build platform 238. The design of each of these components can be varied.

[0091] As with the previous implementation, (i) the build platform 238 can be generally rigid, disk-shaped; (ii) the sidewall 240 can be rigid, generally tubular-shaped; and (iii) the platform mover assembly 242 can move the build platform 238 linearly (e.g., up and down) relative to the sidewall 240. The build platform 238 and the sidewall 240 are similar in design to the corresponding components described above.

[0092] In Figure 2, the platform mover assembly 242 selectively moves the build

platform 238 relative to the sidewall 240. The platform mover assembly 242 can be similar in design to the corresponding component described above.

[0093] The mover connector assembly 244 fixedly connects the platform mover assembly 242 to the build platform 238. Further, in certain implementations, as above, the mover connector assembly 244 is designed to reduce heat generated during the preheating and/or melting of the material 212 on the build platform 228 from being transferred to the platform mover assembly 242.

[0094] In the non-exclusive implementation illustrated in Figure 2, the mover connector assembly 244 includes a thermal insulator 246, a heat dissipation assembly 248, a heat spreader 252, a pusher 254, and a connector rod 250. In this implementation, the thermal insulator 246; the heat dissipation assembly 248, including a heat exchanger 248A that defines a flow channel 248B, and a circulation system 248C (illustrated with a box) that circulates a circulation fluid 248D (illustrated with small triangles) through the flow channel 248B; and the connector rod 250 can be somewhat similar to the corresponding components in the previous implementations. Alternatively, in other implementations, the mover connector assembly 244 can be designed without one or more of such components.

[0095] In this implementation, in order to improve the cooling capability of the circulation fluid 248D used within the circulation system 248C of the heat dissipation assembly 248 such that it does not boil at the cooling interface, the contact area of the flow channel 248B is increased. As non-exclusive examples, the circulation fluid 248D can be water; refrigerants such as Fluorinert, Novec, or Hydrofluoroether; oil or alcohol-based liquids; solvent-based liquids; or other hydrous solutions

[0096] As illustrated, the increased contact area can be accomplished via the heat spreader 252, which has a high planar thermal conductivity and preferably (in certain implementations) a lower axial thermal conductivity. This allows the heat to spread out over a larger heat exchanger 248A before it reaches the cooling circulation fluid 248D, thereby reducing the temperature of the contact interface. In practice, the heat spreader 252 can be formed from a high thermal conductivity material such as copper, or from another suitable material such as a composite, honeycomb, or foam structure having a high planar thermal conductivity and lower axial thermal conductivity. Alternatively, or

additionally, the heat spreader 252 can be in direct contact with the circulation fluid 248D.

[0097] Similar to the previous implementations, the thermal insulator 246, the heat dissipation assembly 248 and the connector rod 250 of the mover connector assembly 244 are again designed to reduce heat generated during the preheating and/or melting of the material 212 on the build platform 228 from being transferred to the platform mover assembly 242. However, in this implementation, as shown, the mover connector assembly 244 further includes the heat spreader 252 and the pusher 254 that are coupled to and positioned substantially between the thermal insulator 246 and the build platform 238 to further reduce heat generated during the preheating and/or melting of the material 212 on the build platform 228 from being transferred to the platform mover assembly 242.

[0098] In this implementation, the thermal insulator 246 (i) is rigid; (ii) physically couples the heat spreader 252 to the heat dissipation assembly 248; and (iii) partly thermally decouples the heat dissipation assembly 248 from the build platform 238. The thermal insulator 246 can be similar to the corresponding component described above.

[0099] The heat dissipation assembly 248 dissipates (removes heat) received from the thermal insulator 246 to reduce the amount of heat transferred to the platform mover assembly 242. The design of the heat dissipation assembly 248 can be varied. As above, the heat dissipation assembly 248 includes (i) the heat exchanger 248A that defines the flow channel 248B; and (ii) the circulation system 248C that circulates the circulation fluid 248D through the flow channel 248B to control the temperature of the heat exchanger 248A. In this design, the heat exchanger 248A is rigid and is secured to the bottom of the thermal insulator 246. Moreover, in this design, the heat exchanger 248A is similar to the corresponding component described above. However, in this design, the heat spreader 252 allows for the heat exchanger 248A to be larger than the heat exchanger 48A described above. In one implementation, the heat exchanger 248A has a cross-sectional area that is larger than a corresponding cross-sectional area of the build platform 238.

[00100] The connector rod 250 connects the heat dissipation assembly 248 to the platform mover assembly 242. In Figure 2, the connector rod 250 is similar to the corresponding component described above.

[00101] As noted above, the heat spreader 252 is configured to allow the heat from the

build platform 238 that has been transmitted through the pusher 254 to spread out to allow for a larger heat exchanger 248A. As a result thereof, the heat spreader 252 spreads the heat and reduces the temperature of the contact interface of the heat exchanger 248A. Additionally, as shown, the heat spreader 252 is physically coupled to and extends between the pusher 254 and the thermal insulator 246.

[00102] The design of the heat spreader 252 can be varied. In certain implementations, the heat spreader 252 is formed from material having a high thermal conductivity material, e.g., greater than 50, 100, 150, 200, 250, 300, or 1000 Watts per meter-Kelvin. In some non-exclusive implementations, the heat spreader 252 can be formed from materials or alloys, including copper, aluminum, alumina, silicon carbide, aluminum nitride, pyrolytic graphite or from one or more other suitable materials. Additionally, in some implementations, the heat spreader 252 can be configured to have a high planar thermal conductivity and a lower axial thermal conductivity. A non-exclusive suitable material for this implementation is a carbon fiber mesh.

[00103] The pusher 254 is rigid and physically couples the heat spreader 252 and the build platform 238. In certain non-exclusive implementations, the pusher 254 is rigid, cylindrical-shaped and has a smaller cross-sectional area than both the build platform 238 and the heat spreader 252. With such design, the heat spreader 252 is better able to allow the heat from the build platform 238 to spread out before it reaches the cooling circulation fluid 248D of the heat dissipation assembly 248. This further reduces the temperature of the contact interface.

[00104] Additionally, the pusher 254 can be formed from any suitable material. For example, in certain non-exclusive implementations, the pusher 254 can be formed from stainless steel, alumina, molybdenum, tungsten, titanium, ceramic, or another suitable material.

[00105] Thus, with such design, the material 212 can be maintained at the desired temperature on the build platform 238, while the heat spreader 252, the thermal insulator 246 and the heat dissipation assembly 248 cooperate to inhibit heat from being transmitted to the platform mover assembly 242. As a result of this thermal isolation, it is easier to maintain the desired high temperature of the material 212 and the object 211 on the build platform 238, which allows for a more accurately built object 211, and for the

desired low temperature of the platform mover assembly 242.

[00106] Figure 3 is a simplified cut-away view of the object 311 and a portion of still another implementation of the material bed assembly 314 that can be used in the processing machine 10 of Figure 1A, or another type of three-dimensional processing machine. In particular, Figure 3 is a simplified cut-away view of another implementation of the build platform assembly 328 supporting the material 312 and the object 311 while the object 311 is being built. In this non-exclusive implementation, the build platform assembly 328 includes a build platform 338, a sidewall 340, a platform mover assembly 342, and a mover connector assembly 344 that connects the platform mover assembly 342 to the build platform 338. The design of each of these components can be varied.

[00107] As with the previous implementations, (i) the build platform 338 can be generally rigid, disk-shaped; (ii) the sidewall 340 can be rigid, generally tubular-shaped; and (iii) the platform mover assembly 342 can move the build platform 338 linearly relative to the sidewall 340. The design of the build platform 338, the sidewall 340, and the platform mover assembly 342 can be similar to the corresponding components described above.

[00108] The mover connector assembly 344 fixedly connects the platform mover assembly 342 to the build platform 338 and is designed to reduce heat generated during the preheating and/or melting of the material 312 on the build platform 328 from being transferred to the platform mover assembly 342.

[00109] In the non-exclusive implementation illustrated in Figure 3, the mover connector assembly 344 includes a thermal insulator 346, a heat dissipation assembly 348, a heat spreader 352, and a connector rod 350. In this implementation, the thermal insulator 346; the heat dissipation assembly 348, including a heat exchanger 348A that defines a flow channel 348B, and a circulation system 348C (illustrated with a box) that circulates a circulation fluid 348D (illustrated with small triangles) through the flow channel 348B; and the connector rod 350 can be somewhat similar to the corresponding components in the previous implementations. In Figure 3, the heat spreader 352 is positioned between the thermal insulator 346 and the heat exchanger 348A. Alternatively, the heat spreader 352 can be in direct contact with the circulation fluid 348D. Alternatively, in other implementations, the mover connector assembly 344 can be designed without one or

more of such components.

[00110] In this implementation, the build platform assembly 328 is configured to (i) decrease the footprint (i.e., the projected area onto the XY plane) of the heat exchanger 348A while having a relatively long flow channel 348B; and (ii) shrink the length of the “pusher”, i.e. the thermal insulator 346 in this implementation. In particular, as illustrated, the contact area established within the heat dissipation assembly 348 can be provided in a stepped configuration where the flow channel 348B of the heat exchanger 348A is effectively “folded” into itself and the maximum diameter of the flow channel 348B in an XY plane can be reduced to fit within the sidewall 340 of the build platform assembly 328 within which the build platform 338 moves in a piston-like manner. More specifically, the heat exchanger 348A and/or the flow channel 348B can include a step 348E that is sized to fit within and be selectively movable relative to the sidewall 340. With this design, the temperature of the material 312 and/or the object 311 can be effectively maintained while also reducing the overall size and weight of the build platform assembly 328. Another way to improve the cooling of the heat exchanger 348A is to have “fins” along the coolant path that provide more surface area for the circulation fluid 348D to touch. Still alternatively, the flow path might be designed so that the circulation fluid 348D flows from the center radially outward to enhance heat transfer and reduce cavitation.

[00111] Similar to the previous implementation, the thermal insulator 346, the heat dissipation assembly 348, the heat spreader 352, and the connector rod 350 of the mover connector assembly 344 are again designed to reduce heat generated during the preheating and/or melting of the material 312 on the build platform 328 from being transferred to the platform mover assembly 342. However, in this implementation, as shown, the thermal insulator 346 is positioned above the heat spreader 352, and between the heat spreader 352 and the build platform 338. Additionally, the thermal insulator 346 is sized and shaped to move within the sidewall 340 during movement of the build platform 338. With such design, the thermal insulator 346 functions as the pusher that is positioned to engage the build platform 338 and cause movement of the build platform 338.

[00112] In one, non-exclusive implementation, the thermal insulator 346 (i) is rigid; (ii) physically couples the heat spreader 352 to the build platform 338; and (iii) partly

thermally decouples the heat dissipation assembly 348 from the build platform 338. With such design, as above, the thermal insulator 246 thermally isolates the heat dissipation assembly 348 from the build platform 338, and reduces the amount of heat transferred from the build platform 338 to the heat dissipation assembly 348.

[00113] The design of the thermal insulator 346 can be similar to the corresponding component described above. However, in Figure 3, the thermal insulator 346 is a cylindrical-shaped block with a raised central portion that somewhat coincides with the stepped design of the flow channel 348B and/or the heat spreader 352. Additionally, as noted, the thermal insulator 346 is fixedly attached to and positioned between the build platform 338 and the heat spreader 352. Alternatively, for example, the thermal insulator 346 can be disk shaped and a separate, cylindrical shaped pusher (not shown) can be utilized.

[00114] The heat spreader 352 is configured to allow the heat from the build platform 338 that has been transmitted through the thermal insulator 346 to spread out before it reaches the heat dissipation assembly 348, thereby reducing the temperature of the contact interface. Additionally, as shown, the heat spreader 352 is physically coupled to and extends between the thermal insulator 346 and the flow channel 348B of the heat dissipation assembly 348. The design of the heat spreader 352 can be somewhat similar to the corresponding component described above. However, in Figure 3, the heat spreader 352 has a stepped design (e.g., cup shaped) that is configured to coincide with the stepped design of the flow channel 348B of the heat exchanger 348A. Further, unlike the embodiment of Figure 2, where it may be desired that the heat spreader 252 have high thermal conductivity in the plane and low thermal conductivity in the Z direction, in the embodiment of Figure 3 it is may be desired that the heat spreader 352 have high thermal conductivity in every direction.

[00115] The heat dissipation assembly 348 dissipates (removes) heat received from the heat spreader 352 and the thermal insulator 346 reduces the amount of heat transferred to the platform mover assembly 342. The heat dissipation assembly 348 can again include (i) the heat exchanger 348A that defines the flow channel 348B; and (ii) the circulation system 348C that circulates the circulation fluid 348D through the flow channel 348B to control the temperature of the heat exchanger 348A. In this design, the heat

exchanger 348A and the circulation system 348C are somewhat similar to the corresponding components described above. However, in Figure 3, the heat exchanger 348A is designed to have a folded configuration so that the circulation fluid 348D flows upward, around, and down through the flow channel 348B before it exits the heat dissipation assembly 348. As noted, this allows the footprint of the heat dissipation assembly 348 to be smaller while also maintaining the high contact area and longer flow channel 348B. Further, the flow channel 348B of the heat dissipation assembly 348 can also now be pushed into the housing defined by the sidewall 340 and the build platform assembly 328 no longer requires a long pusher such as is included in the implementation shown in Figure 2.

[00116] The connector rod 350 can be similar to the corresponding component described above.

[00117] With the present design, the material 312 can again be maintained at the desired high temperature on the build platform 338, while the platform mover assembly 342 is maintained at the desired low temperature and the thermal insulator 346, the heat spreader 352, and the heat dissipation assembly 348 cooperate to reduce the amount of heat transfer. As a result of this thermal isolation, it is easier to maintain the desired temperature of the material 312 and the object 311 on the build platform 338, which allows for a more accurately built object 311.

[00118] Figure 4A is a simplified perspective view of the object 411 (illustrated as a box), and another implementation of the material bed assembly 414 that supports the object 411 (and material), and the assembly mover assembly 425 that moves the material bed assembly 414. The material bed assembly 414 and the assembly mover assembly 425 can be used in the processing machine 10 of Figure 1A, or another type of three-dimensional processing machine. Figure 4B is a simplified cut-away view of the material bed assembly 414, the object 411, and the assembly mover assembly 425 of Figure 4A.

[00119] With reference to Figures 4A and 4B, in this non-exclusive implementation, the material bed assembly 414 includes (i) the first support frame 426; (ii) one or more build platform assemblies 428 (only one is illustrated in Figure 4A) that supports the object 411 while being formed; (iii) the second support frame 430; and (iv) the frame coupler assembly 432 (partly illustrated in phantom) that physically couples the first support frame

426 to the second support frame 430. These components are somewhat similar to the corresponding components described above.

[00120] In this non-exclusive example, the first support frame 426 is rigid, generally disk-shaped, and supports the build platform assembly 428. Additionally, the first support frame 426 can include one or more frame counterweights 426B (one is shown) that compensate for the weight of the build platform assembly 428 and/or the object 411 to more effectively balance the first support frame 426.

[00121] The build platform assembly 428 is a little different from the corresponding component described above. More specifically, in this implementation, the build platform assembly 428 includes (i) the disk-shaped build platform 438; (ii) a cylindrical-shaped platform shaft 438A that is fixed to and extends downward from the build platform 438; and (iii) a platform bearing assembly 438B that rotatably connects the platform shaft 438A to the first support frame 426. As a result thereof, in this non-exclusive implementation, the build platform 438 is rotatably supported by the first support frame 426 and rotated relative to the first support frame 426, but is not moved linearly relative to the first support frame 426. In one non-exclusive implementation, the build platform 438 is movably supported and thermally connected to the first support frame 426. For example, the build platform 438 and the first support frame is thermally connected via a lubrication material having high thermal conductivity, such as liquid metal.

[00122] The second support frame 430 is rigid, is positioned below the first support frame 426, and supports the first support frame 426. In this non-exclusive implementation, the second support frame 430 includes (i) an annular disk-shaped lower frame 430A; and (ii) a step-shaped, annular flange 430B that is secured to the lower frame 430A. Alternatively, for example, the second support frame 430 can be designed without the annular flange 430B.

[00123] The frame coupler assembly 432 physically couples the first support frame 426 to the second support frame 430 and maintains the support frames 426, 430 spaced apart. In the non-exclusive implementation in Figures 4A and 4B, the frame coupler assembly 432 physically couples the first support frame 426 to the second support frame 430 in a kinematic fashion. In this implementation, the platform coupler assembly 432 (i) maintains the precise alignment between the support frames 426, 430, while allowing for

relative thermal expansion between the support frames 426, 430; and/or (ii) inhibits heat transfer between the support frames 426, 430.

[00124] There are many different ways to kinematically couple the first support frame 426 to the second support frame 430. Figure 4C is a simplified perspective view of one, non-exclusive implementation of the platform coupler assembly 432. With reference to Figures 4A-4C, the platform coupler assembly 432 is a canonical example of a kinematic coupling that consists of three radial v-grooves in one part that mate with three hemispheres in another part. The three v-grooves are arranged radially with respect to a central axis 426C. In this design, each hemisphere has two contact points for a total of six contact points, enough to constrain in all six degrees of freedom. A non-exclusive alternative design consists of three hemispheres on one part that fit respectively into a tetrahedral dent (or a cone), a v-groove, and a flat in the other.

[00125] More specifically, in this non-exclusive implementation, the frame coupler assembly 432 includes three spaced apart connectors 432A that extend between the support frames 426, 430. Further, each connector 432A includes (i) a first connector housing 432B that defines a semi-spherical aperture 432C (illustrated in phantom); (ii) a second connector housing 432D that defines a “V”-shaped groove 432E; and (iii) a rigid sphere 432F that is sized and positioned to partly fit into the semi-spherical aperture 432C and the groove 432E.

[00126] In this design, the first connector housing 432B is fixedly secured to one of the support frames 426, 430, and the second connector housing 432D is fixedly secured to the other of the support frames 426, 430. In the illustrated implementation, the first connector housing 432B is fixedly secured to the first support frame 426, and the second connector housing 432D is fixedly secured to the second support frame 430. Alternatively, the first connector housing 432B can be fixedly secured to the second support frame 430, and the second connector housing 432D can be fixedly secured to the first support frame 426. The plurality of the frame coupler assemblies 432 may be arranged at equal angles along the circumference centered on the center axis 426C.

[00127] However, it should be noted that other kinematic designs are possible. For example, for each connector 432A, a semi-spherical ball can be directly secured to the first support frame 426 and the “V”-shaped groove 432E can be directly formed in the

second support frame 430.

[00128] With the present design, the connectors 432A can be oriented such that the “V”-shaped grooves 432E point toward a center axis 426C of the first support frame 426. In other words, the grooves 432E are oriented such that the longitudinal directions cross the rotation direction. The connectors 432A couple both axial and radial motion from the assembly mover assembly 425 to the first support frame 426. This design has numerous advantages, including, but not limited to: (i) the spheres 432F allow for free thermal expansion radially of the first support frame 426 relative to the second support frame 430; (ii) the spheres 432F provide good position repeatability of the first support frame 426 to the second support frame 430 and the assembly mover assembly 425; (iii) the spheres 432F allow for easy assembly and disassembly; (iv) the first support frame 426 is coupled to the second support frame 430 solely using the weight of the first support frame 426; and (v) the connectors 432A have no “backlash”, and rotational motion in both directions will have no backlash. Moreover, due to physical contact happening only at six small spots (two per sphere 432F within each “V”-shaped groove 432E), the connectors 432A create a very large thermal resistance path for heat transfer from the first support frame 426 to the second support frame 430. This allows the temperature of the first support frame 426 to be more isolated. In summary, the problem of repeatably mounting the first support frame 426 to the assembly mover assembly 425 is solved by using a kinematic, frame coupler assembly 432 to couple the first support frame 426 to the second support frame 430 and, thus, to the assembly mover assembly 425.

[00129] In one implementation, the connectors 432A can be made of materials that are hard and have a high melting point. As non-exclusive examples, stainless steel or hardened steels can be utilized. Ceramics may also work, but they are brittle and could crack.

[00130] The design of the assembly mover assembly 425 can be varied to achieve the desired movement requirements of the build platform 438. In the non-exclusive implementation of Figures 4A and 4B, the assembly mover assembly 425 is controlled to selectively (i) rotate the support frames 426, 430 and the build platform 438 about the central axis 426C; (ii) move the support frames 426, 430 and the build platform 438 linearly along the central axis 426C; and (iii) rotate the build platform 438 relative to the

first support frame 426 about the platform axis 438C. In one non-exclusive example, the assembly mover assembly 425 (i) rotates the support frames 426, 430 and the build platform 438 about the central axis 426C in a first rotational direction; (ii) rotates the build platform 438 relative to the first support frame 426 about the platform axis 438C in a second rotational direction that is opposite to the first rotational direction; and (iii) vertically lowers the support frames 426, 430 and the build platform 438 linearly along the central axis 426C when each new material layer is added to the build platform 438.

[00131] In one implementation, the assembly mover assembly 425 includes (i) a first actuator 425A that rotates the support frames 426, 430 and the build platform 438 about the central axis 426C; (ii) a second actuator 425B that moves the support frames 426, 430 and the build platform 438 linearly along the central axis 426C; and (iii) a third actuator 425C that rotates the build platform 438 relative to the first support frame 426 about the platform axis 438C. For example, the assembly mover assembly 425 can include multiple rotary and linear motors.

[00132] Moreover, a mover connector assembly 460 can physically couple the assembly mover assembly 425 to the components of the material bed assembly 414. As a non-exclusive example, the mover connector assembly 460 can include (i) a first connector assembly 462 that mechanically connects the first actuator 425A to the second support frame 430; and (ii) a second connector assembly 464 that mechanically connects the third actuator 425C to the build platform assembly 428. The design of each of these connector assemblies 462, 464 can be varied.

[00133] Optionally, in the non-exclusive implementation of Figure 4B, the first connector assembly 462 can include a tubular-shaped thermal insulator 462A and a tubular-shaped heat dissipation system 462B that are somewhat similar to the corresponding components described above in reference to Figure 1C. Alternatively, the first connector assembly 462 can be designed without one or both of the thermal insulator 462A and the heat dissipation system 462B.

[00134] In the non-exclusive implementation of Figure 4B, the thermal insulator 462A (i) is rigid; (ii) is secured to the bottom of the second support frame 430; and (iii) thermally isolates the heat dissipation assembly 462B from the second support frame 430, and reduces the amount of heat transferred from the second support frame 430 to the heat

dissipation assembly 462B. The thermal insulator 462A can be made of a material having a relatively low thermal conductivity.

[00135] Further, in Figure 4B, the heat dissipation assembly 462B dissipates (removes) heat received from the thermal insulator 462A to reduce the amount of heat transferred to the assembly mover assembly 425. As a non-exclusive example, the heat dissipation assembly 462B can include (i) a heat exchanger 462C that defines a flow channel (not shown); and (ii) a circulation system 462D (illustrated with a box) that circulates a circulation fluid (not shown) through the flow channel to control the temperature of the heat exchanger 462C. In this design, the heat exchanger 462C is rigid and is secured to the bottom of the thermal insulator 462A. Alternatively, for example, the heat dissipation assembly 462B can include another type of chiller, such as a refrigeration system. Still alternatively, as described below in reference to Figure 8, a portion of the first connector assembly 462 can be cooled and/or temperature controlled utilizing a housing and a heat exchanger.

[00136] Alternatively, or additionally, the temperature of the assembly mover assembly 425 can be controlled in a different fashion. More specifically, for example, the flange 430B of the second support frame 430 can be made of a material having a relatively low thermal conductivity. In this design, the flange 430B acts as a thermal insulator.

[00137] Additionally, or alternatively, the circulation system 462D can direct the circulation fluid through or near the first support frame 426 and/or the second support frame 430 to directly control the temperature of and/or cool the first support frame 426 and/or the second support frame 430. This design, is described in more detail with reference to Figure 7 below.

[00138] Further, in the non-exclusive implementation of Figure 4B, the second connector assembly 464 can include (i) a cylindrical-shaped connector shaft 464A that is coupled to the third actuator 425C; (ii) a first pulley 464B that is secured to the connector shaft 464A; (iii) a second pulley 464C that is secured to the platform shaft 438A; and (iv) a belt 464D that connects the first pulley 464B to the second pulley 464C. With this design, rotation of the connector shaft 464A results in rotation of the platform shaft 438A and the build platform 438. Alternatively, the third actuator 425C can be mechanically coupled to the build platform 438 in a different fashion.

[00139] Figure 5 is a simplified side view of the object 511, and a portion of still another implementation of the material bed assembly 514 that can be used in the processing machine 10 of Figure 1A, or another type of three-dimensional processing machine. In particular, in this implementation, the material bed assembly 514 includes (i) the first support frame 526; (ii) the second support frame 530; and (iii) the frame coupler assembly 532 that physically couples the first support frame 526 and the second support frame 530. These components are somewhat similar to the corresponding components described above. Figure 5 also illustrates a portion of the assembly mover assembly 525 that moves the material bed assembly 514, and a portion of the environmental chamber 523 in which the material bed assembly 514 can be retained.

[00140] In this non-exclusive example, the first support frame 526 can be rigid, generally disk-shaped, and supports one or more build platform assemblies (not shown in Figure 5). Additionally, the first support frame 526 can include one or more frame counterweights (not shown) that compensate for the weight of the build platform assemblies and/or the object 511 to more effectively balance the first support frame 526.

[00141] The second support frame 530 is rigid, is positioned below the first support frame 526, and supports the first support frame 526. In this non-exclusive implementation, the second support frame 530 is also rigid and generally disk-shaped.

[00142] In this implementation, the problem of coupling vertical and rotational actuation to a rotary turntable while also allowing for radial thermal expansion of the turntable is solved by using radial flexures to allow for the turntable plate (first support frame 526) to expand about its center freely while still constrained in all other degrees of freedom. In particular, the present implementation outlines a method to support the first support frame 526 of a rotary stage vertically while still allowing it to expand radially. It is appreciated that the present implementation is advantageous over no support because it will reduce build errors related to gravity sag of the first support frame 526. The present implementation is also advantageous over a rigid column because it allows the first support frame 526 to expand freely radially, which minimizes error due to thermal distortion/warping of the first support frame 526.

[00143] The frame coupler assembly 532 physically couples the first support frame 526 to the second support frame 530 and maintains the support frames 526, 530 spaced

apart. In the non-exclusive implementation in Figure 5, the frame coupler assembly 532 physically couples the first support frame 526 to the second support frame 530 with a plurality (e.g., at least three) flexures 566 (four flexures 566 are shown in Figure 5). In this implementation, the platform coupler assembly 532 (i) maintains the precise alignment between the support frames 526, 530, while allowing for relative thermal expansion between the support frames 526, 530; and/or (ii) inhibits heat transfer between the support frames 526, 530.

[00144] The frame coupler assembly 532 can include any suitable number of flexures 566. For example, in the non-exclusive implementation illustrated in Figure 5, the frame coupler assembly 532 includes four flexures 566 that are spaced apart from one another, and each are coupled to and extend between the first support frame 526 and the second support frame 530. Alternatively, the frame coupler assembly 532 can include greater than four flexures 566 or only three flexures 566 that are configured to provide the desired coupling between the first support frame 526 and the second support frame 530. The flexures 566 may be arranged the circumference centered on the center axis (not shown). The flexures 566 allow the radial stiffness of the frame coupler assemblies 532 to be lower than the circumferential stiffness.

[00145] In one implementation, the flexures 566 can be spaced apart from one another substantially equally circumferentially about the circumference of the first support frame 526 and/or the second support frame 530. Alternatively, the flexures 566 can be other than equally spaced apart from one another circumferentially about the circumference of the first support frame 526 and/or the second support frame 530. Additionally, each of the flexures 566 can be positioned any desired distance from the center (and the perimeter) of the first support frame 526 and the second support frame 530 to provide the desired support and alignment between the first support frame 526 and the second support frame 530, while still allowing for relative thermal expansion radially between the support frames 526, 530.

[00146] The design of the flexures 566 can be varied. In certain implementations, the flexures 566 are similar or identical to each other, and the flexures 566 are arranged in rotational symmetry about a common rotational axis 531 for the first support frame 526 and the second support frame 530, such that differential thermal expansion does not

cause the center of the first support frame 526 to shift relative to the second support frame 530. The bending axes of the flexures 566 can be arranged in a plane parallel to the rotation axis 531, wherein the bending axes are tangential to the rotation axis 531. Flexures 566 may be monolithic as shown in Figure 5 or may be blade-like. One or more of the flexures 566 can be made of stainless steel or other rigid materials. In the nonexclusive implementation of Figure 5 (and Figure 6) the flexures 566 as illustrated as distinct parts. In an alternative embodiment, two or more of the flexures 566 can be formed (e.g., by wire-EDM) as a single part. Additionally, or alternatively, one or more of the flexures 566 can be formed into either of the first support frame 526 or the second support frame 530.

[00147] In another, non-exclusive implementation, the flexures 566 can be similar to a leaf spring. Alternatively, the flexures 566 can have another suitable design. In various implementations, the flexures 566 are configured to be rigid in the vertical direction (i.e. along and/or parallel to the Z axis)), rigid in the circumferential direction (tangentially), and soft or flexible in the radial direction. With such design, the flexures 566 are able to maintain the precise alignment between the support frames 526, 530, while allowing for relative thermal radial expansion between the support frames 526, 530.

[00148] Also illustrated in Figure 5, the frame coupler assembly 532 can optionally include a support post 568, which can be positioned to be coupled to a center of each of the first support frame 526 and the second support frame 530. In one implementation, the support post 568 can be configured to have a relatively small cross-sectional area to minimize contact surface area, while still providing desired support for the first support frame 526 relative to the second support frame 530 and inhibiting sagging near the center of the first support frame 526. For example, the support post 568 is rigid and non-exclusive examples of suitable materials include steel, stainless steel, alumina, molybdenum, tungsten, titanium, or ceramic materials. The number of support posts 568 is not limited to one. At least one support post among a plurality of support posts 568 may be contact with the first support frame 568 such that the support post 568 supports the weight of the first support frame 526 and is variable in position in the XY plane with the first support frame 526.

[00149] As noted, the first support frame 526 is configured to support the build

platform(s) and the object 511. As such, the first support frame 526 acts as both a structural support and temperature sink for the object 511. In some implementations, it can be desired to maintain a temperature of the first support frame at approximately five hundred degrees Celsius during the build process in order to ensure best build quality of the object 511. The second support frame 530 in conjunction with the frame coupler assembly 532 exists both as a support structure for the first support frame 526 to prevent gravity sag and also as a temperature buffer between the first support frame 526 and the bottom of the environmental chamber 523 (only partly illustrated in Figure 5), which can be at or close to room temperature. Due to the high temperature of the first support frame 526 at steady state, in a certain implementation, a first support frame 526 having an eight hundred millimeter diameter and made of stainless steel 316 can be expected to expand in excess of two millimeters radially. To allow for the first support frame 526 to thermally expand while still supporting the structure from the second support frame 530, the flexures 566 of the frame coupler assembly 532 have their compliant degree of freedom in the radial direction of the first support frame 526. The flexures 566 will allow the first support frame 526 to expand radially relative to the second support frame 530, which will be at a different temperature, while still being supported vertically and tangentially. As non-exclusive examples, the difference in temperature between the support frames 526, 530 can be approximately 100, 200, 300 or more degrees Celsius.

[00150] Alternatively, or additionally, the mover connector assembly 560 can include a thermal insulator (not shown) and/or a heat dissipation assembly (not shown).

[00151] Additionally, or alternatively, the temperature of the first support frame 526 and/or the second support frame 530 can be actively controlled.

[00152] Figure 6 is a simplified cut-away view of the object 611, yet another implementation of the material bed assembly 614 that supports the object 611, and the assembly mover assembly 625 that moves the material bed assembly 614. The material bed assembly 614 can be used in the processing machine 10 of Figure 1A, or another type of three-dimensional processing machine.

[00153] In this non-exclusive implementation, the material bed assembly 614 is somewhat similar to the implementation illustrated and described above in relation to Figures 4A and 4B. In particular, in this implementation, the material bed assembly 614

again includes (i) the first support frame 626; (ii) one or more build platform assemblies 628 (only one is illustrated in Figure 6) that support the object 611 while being formed; and (iii) the second support frame 630. Additionally, as illustrated, the material bed assembly 614 further includes a frame coupler assembly 632 that is substantially similar to the implementation illustrated and described in relation to Figure 5, which physically couples the first support frame 626 to the second support frame 632.

[00154] In this non-exclusive example, the first support frame 626 is rigid, generally disk-shaped, and supports the build platform assembly 628. Additionally, the first support frame 626 can include one or more frame counterweights 626B (one is shown) that compensate for the weight of the build platform assembly 628 and/or the object 611 to more effectively balance the first support frame 626.

[00155] The build platform assembly 628 includes (i) the disk-shaped build platform 638; (ii) a cylindrical-shaped platform shaft 638A that is fixed to and cantilevers downward from the build platform 638; and (iii) a platform bearing assembly 638B that rotatably connects the platform shaft 638A to the first support frame 626. As a result thereof, in this non-exclusive implementation, the build platform 638 is again rotated relative to the first support frame 626, but is not moved linearly relative to the first support frame 626.

[00156] The second support frame 630 is rigid, is positioned below the first support frame 626, and supports the first support frame 626. In this non-exclusive implementation, the second support frame 630 includes (i) an annular disk-shaped lower frame 630A; and (ii) a step-shaped, annular flange 630B that is secured to the lower frame 630A.

[00157] The frame coupler assembly 632 physically couples the first support frame 626 to the second support frame 630 and maintains the support frames 626, 630 spaced apart. In one implementation, the platform coupler assembly 632 (i) maintains the precise alignment between the support frames 626, 630, while allowing for relative thermal expansion between the support frames 626, 630; and/or (ii) inhibits heat transfer between the support frames 626, 630.

[00158] In one implementation, the frame coupler assembly 632 physically couples the first support frame 626 to the second support frame 630 with a plurality (e.g. at least three) flexures 666 for an approximate kinematic connection. In such implementation, the

flexures 666 are positioned relative to one another and relative to the support frames 626, 630 to (i) maintain the precise alignment between the support frames 626, 630, while allowing for relative thermal expansion between the support frames 626, 630; and/or (ii) inhibit heat transfer between the support frames 626, 630.

[00159] The frame coupler assembly 632 can include any suitable number of flexures 666. For example, in one implementation, the frame coupler assembly 632 includes four flexures 666 that are spaced apart from one another, and each are coupled to and extend between the first support frame 626 and the second support frame 630. Alternatively, the frame coupler assembly 632 can include greater than four flexures 666 or only three flexures 666 that are configured to provide the desired coupling between the first support frame 626 and the second support frame 630.

[00160] In one implementation, the flexures 666 can be spaced apart from one another substantially equally circumferentially about the circumference of the first support frame 626 and/or the second support frame 630. Alternatively, the flexures 666 can be other than equally spaced apart from one another circumferentially about the circumference of the first support frame 626 and/or the second support frame 630. Additionally, each of the flexures 666 can be positioned any desired distance from the center (and the perimeter) of the first support frame 626 and the second support frame 630 to provide the desired support and alignment between the first support frame 626 and the second support frame 630, while still allowing for relative thermal expansion radially between the support frames 626, 630.

[00161] The number, design and/or positioning of the flexures 666 can be similar to that described above in reference to Figure 5.

[00162] In one implementation, the flexures 666 are configured to be rigid in the vertical direction (i.e. along and/or parallel to the Z axis)), rigid in the circumferential direction (tangentially), and soft or flexible in the radial direction. With such design, the flexures 666 are able to maintain the precise alignment between the support frames 626, 630, while allowing for relative thermal radial expansion between the support frames 626, 630.

[00163] As illustrated, the frame coupler assembly 632 can further include a support post 668, which can be positioned to be coupled near and/or about a center of each of the first support frame 626 and the second support frame 630. In one implementation,

the support post 668 is rigid and tubular shaped. Further, the support post 668 can be configured to have a relatively small cross-sectional area to minimize contact surface area, while still providing desired support for the first support frame 626 relative to the second support frame 630 and inhibiting sagging near the center of the first support frame 626.

[00164] The design of the assembly mover assembly 625 can be varied to achieve the desired movement requirements of the build platform 638. In the non-exclusive implementation of Figure 6, the assembly mover assembly 625 is similar to the corresponding component described above and illustrated in Figure 4B. In this implementation, the assembly mover assembly 625 is controlled to selectively (i) rotate the support frames 626, 630 and the build platform 638 about the central axis 626C; (ii) move the support frames 626, 630 and the build platform 638 linearly along the central axis 626C; and (iii) rotate the build platform 638 relative to the first support frame 626 about the platform axis 638C. In one non-exclusive example, the assembly mover assembly 625 (i) rotates the support frames 626, 630 and the build platform 638 about the central axis 626C in a first rotational direction; (ii) rotates the build platform 638 relative to the first support frame 626 about the platform axis 638C in a second rotational direction that is opposite to the first rotational direction; and (iii) vertically lowers the support frames 626, 630 and the build platform 638 linearly along the central axis 626C when each new material layer is added to the build platform 638. In one implementation, the assembly mover assembly 625 includes (i) a first actuator 625A that rotates the support frames 626, 630 and the build platform 638 about the central axis 626C; (ii) a second actuator 625B that moves the support frames 626, 630 and the build platform 638 linearly along the central axis 626C; and (iii) a third actuator 625C that rotates the build platform 638 relative to the first support frame 626 about the platform axis 638C. For example, the assembly mover assembly 625 can include multiple rotary and linear motors.

[00165] Moreover, a mover connector assembly 660 can physically couple the assembly mover assembly 625 to the components of the material bed assembly 614. As a non-exclusive example, the mover connector assembly 660 can include (i) a first connector assembly 662 that mechanically connects the first actuator 625A to the second support frame 630; and (ii) a second connector assembly 664 that mechanically connects

the third actuator 625C to the build platform assembly 628. The design of each of these connector assemblies 662, 664 can be varied.

[00166] In one implementation, the first connector assembly 662 can include a tubular-shaped thermal insulator 662A and a tubular-shaped heat dissipation system 662B that are similar to the corresponding components described above in reference to Figure 4B. Alternatively, the first connector assembly 662 can be designed without one or both of the thermal insulator 662A and the heat dissipation system 662B.

[00167] In Figure 6, in one, non-exclusive implementation, the thermal insulator 662A (i) is rigid; (ii) is secured to the bottom of the second support frame 630; and (iii) thermally isolates the heat dissipation assembly 662B from the second support frame 630, and reduces the amount of heat transferred from the second support frame 630 to the heat dissipation assembly 662B. The thermal insulator 662A can be made of a material having a relatively low thermal conductivity.

[00168] Further, in Figure 6, the heat dissipation assembly 662B dissipates heat received from the thermal insulator 662A to reduce the amount of heat transferred to the assembly mover assembly 625. As a non-exclusive example, the heat dissipation assembly 662B can include (i) a tubular shaped heat exchanger 662C that defines a flow channel (not shown); and (ii) a circulation system 662D (illustrated with a box) that circulates a circulation fluid (not shown) through the flow channel to control the temperature of the heat exchanger 662C. In this design, the heat exchanger 662C is rigid and is secured to the bottom of the thermal insulator 662A. Alternatively, for example, the heat dissipation assembly 662B can include another type of chiller, such as a refrigeration system. Still alternatively, as described below in reference to Figure 8, a portion of the first connector assembly 662 can be cooled and/or temperature controlled utilizing a housing and a heat exchanger.

[00169] Alternatively, or additionally, the temperature of the assembly mover assembly 625 can be controlled in a different fashion. More specifically, for example, the flange 630B of the second support frame 630 can be made of a material having a relatively low thermal conductivity. In this design, the flange 630B acts as a thermal insulator.

[00170] Additionally, or alternatively, the circulation system 662D can direct the circulation fluid through or near the first support frame 626 and/or the second support

frame 630 to directly control the temperature of and/or cool the first support frame 626 and/or the second support frame 630. This design, is described in more detail with reference to Figure 7 below.

[00171] Further, in one implementation, the second connector assembly 664 can include (i) a cylindrical-shaped connector shaft 664A that is coupled to the third actuator 625C; (ii) a first pulley 664B that is secured to the connector shaft 664A; (iii) a second pulley 664C that is secured to the platform shaft 638A; and (iv) a belt 664D that connects the first pulley 664B to the second pulley 664C. With this design, rotation of the connector shaft 664A results in rotation of the platform shaft 638A and the build platform 638. Alternatively, the third actuator 625C can be mechanically coupled to the build platform 638 in a different fashion.

[00172] Figure 7 is a simplified cut-away view of another implementation of the material bed assembly 714 that can be used in the processing machine 10 of Figure 1A, or another type of three-dimensional processing machine. In this non-exclusive implementation, the material bed assembly 714 is somewhat similar to the implementation illustrated and described above in relation to Figure 6. In particular, in this implementation, the material bed assembly 714 again includes (i) the first support frame 726; (ii) one or more build platform assemblies 728 (only one is illustrated in Figure 7) that support the object (not shown in Figure 7) while being formed; (iii) the second support frame 730; and (iv) the frame coupler assembly 732 that can be substantially similar to the corresponding components described above. However, in Figure 7, a temperature of the support frames 726, 730 is actively controlled.

[00173] The assembly mover assembly is not shown in Figure 7. However, the assembly mover assembly can be similar to the corresponding component described above and illustrated in Figure 6. For example, in this implementation, the assembly mover assembly can be controlled to selectively (i) rotate the support frames 726, 730 and the build platform 738 about the central axis 726C; (ii) move the support frames 726, 730 and the build platform 738 linearly along the central axis 726C; and (iii) rotate the build platform 738 relative to the first support frame 726 about the platform axis 738C.

[00174] Moreover, the mover connector assembly 760 can physically couple the assembly mover assembly to the components of the material bed assembly 714.

Somewhat similar to designs described above, the mover connector assembly 760 can include (i) a first connector assembly 762 that mechanically connects the first actuator (not shown in Figure 7) to the second support frame 730; and (ii) a second connector assembly 764 that mechanically connects the third actuator (not shown in Figure 7) to the build platform assembly 728. In Figure 7, the first connector assembly 762 is tubular shaped, and the second connector assembly 764 is also tubular shaped and positioned within the first connector assembly 762.

[00175] In this design, optionally, one or more of the frame coupler assembly 732, the second support frame 730, and the first connector assembly 762 can be made of a material having a relatively low thermal conductivity, and can function as a thermal insulator.

[00176] Additionally, and optionally, the material bed assembly 714 can include a temperature control system 780 for actively controlling the temperature of and/or removing heat from one or both of the support frames 726, 730. The temperature control system 780 can also be referred to as a heat dissipation assembly.

[00177] In the simplified, non-exclusive implementation illustrated in Figure 7, the temperature control system 780 includes (i) a first frame heat exchanger 782 that is thermally connected to the first support frame 726; (ii) a second frame heat exchanger 784 that is thermally connected to the second support frame 730; (iii) a frame circulation system 786; and (iv) a conduit assembly 788 that connects the circulation system 786 in fluid communication with the frame heat exchangers 782, 784. The design of each of these components can be varied. Further, for example, the temperature control system 780 can be designed to control the temperature of and/or remove heat from only one of the support frames 726, 730.

[00178] The frame circulation system 786 can circulate a frame circulation fluid 786A (illustrated with small squares) through the flow channels (not shown in Figure 7) in the heat exchangers 782, 784 to control the temperature of and/or remove heat from the respective support frames 726, 730. In this design, each heat exchanger 782, 784 can define one or more separate flow channels. Alternatively, one or both heat exchangers 782, 784 can be integrated into the respective support frames 726, 730 with the fluid passageways formed within the respective support frames 726, 730. The heat

exchangers 782, 784 can include materials with relatively high thermal conductivity. Further, the frame circulation system 786 can include one or more pumps, reservoirs, chillers, etc., to control the flow rate and/or temperature of the circulation fluid 786A.

[00179] The conduit assembly 788 connects the circulation system 786 in fluid communication with the frame heat exchangers 782, 784. In certain designs, the conduit assembly 788 connects the circulation system 786 in fluid communication with the frame heat exchangers 782, 784 while allowing the support frames 726, 730 to rotate relative to the frame circulation system 786.

[00180] In the simplified, non-exclusive implementation of Figure 7, the conduit assembly 788 includes (i) a supply conduit 788A that is connected to the frame circulation system 786; (ii) a return conduit 788B that is connected to the frame circulation system 786; and (iii) a slip ring connector 788C. In this design, the conduits 788A, 788B extend through the center of the second connector assembly 764. Further, the slip ring connector 788C is a hydraulic connector that includes a connector block 788D is secured to the first support frame 726, and a conduit block 788E. Moreover, (i) the connector block 788D is connected with one or more first conduits 788F to the first frame heat exchanger 782; (ii) the connector block 788D is connected with one or more second conduits 788G to the second frame heat exchanger 784; and (iii) the conduit block 788E is connected in fluid communication with the supply conduit 788A and the return conduit 788B. The frame heat exchangers 782, 784 can be connected in parallel or in series to the connector block 788D. Further, the connector block 788D and the conduit block 788E form a hydraulic connector that allows the connector block 788D to rotate relative to the conduit block 788E, the supply conduit 788A and the return conduit 788B.

[00181] It should be noted that the frame circulation system 786 can optionally include one or more temperature sensors 786B that monitor the temperature of one or both of the support frames 726, 730, or other locations. These temperature sensors 786B allow for closed loop control of the frame circulation system 786.

[00182] Additionally, it should be noted that temperature of the first connector assembly 762 can be actively controlled with a heat dissipation assembly. The temperature control system 780 may control the temperature depending on the amount of heat transferred to the material 12 on the build platform 38. For example, the temperature control system

780 may control the temperature depending on at least the irradiation time of the energy from the energy system 22, the pre-heat device 16, or the post-heat device. Further, the temperature control system 780 may control the temperature depending on the z-position of the build platform 38.

[00183] Figure 8 is a simplified cut-away view of still yet another implementation of the material bed assembly 814 that can be used in the processing machine 10 of Figure 1A, or another type of three-dimensional processing machine. In this non-exclusive implementation, the material bed assembly 814 is somewhat similar to the implementation illustrated and described above in relation to Figure 6. In particular, in this implementation, the material bed assembly 814 again includes (i) the first support frame 826; (ii) one or more build platform assemblies 828 (only one is illustrated in Figure 8) that support the object (not shown in Figure 8) while being formed; (iii) the second support frame 830; and (iv) the frame coupler assembly 832 that can be substantially similar to the corresponding components described above. It should be noted that a portion of environmental chamber 823 is also illustrated in Figure 8.

[00184] The assembly mover assembly is not shown in Figure 8. However, the assembly mover assembly can be similar to the corresponding component described above and illustrated in Figure 6. For example, in this implementation, the assembly mover assembly can be controlled to selectively (i) rotate the support frames 826, 830 and the build platform 838 about the central axis 826C; (ii) move the support frames 826, 830 and the build platform 838 linearly along the central axis 826C; and (iii) rotate the build platform 838 relative to the first support frame 826 about the platform axis 838C.

[00185] Moreover, the mover connector assembly 860 can physically couple the assembly mover assembly to the components of the material bed assembly 814. Somewhat similar to designs described above, the mover connector assembly 860 can include (i) a first connector assembly 862 that mechanically connects the first actuator (not shown in Figure 8) to the second support frame 830; and (ii) a second connector assembly 864 that mechanically connects the third actuator (not shown in Figure 8) to the build platform assembly 828. In Figure 8, the first connector assembly 862 is tubular shaped, and the second connector assembly 864 is cylindrical shaped and positioned within the first connector assembly 862.

[00186] Additionally, and optionally, in Figure 8, a temperature of the first connector assembly 862 can be actively controlled. More specifically, in this design, the material bed assembly 814 can include a connector temperature control system 890 for actively controlling the temperature of and/or removing heat from one or both of the connector assemblies 862, 864. The connector temperature control system 890 can also be referred to as a heat dissipation assembly.

[00187] In the simplified, non-exclusive implementation illustrated in Figure 8, the connector temperature control system 890 includes (i) a rotary fluid bearing housing 892 that encircles a portion of the first connector assembly 862; (ii) a fluid bearing source 894 (illustrated as a box); (iii) a connector heat exchanger 896 that is thermally coupled to the fluid bearing housing 892; and (iv) a housing circulation system 898. The design of each of these components can be varied.

[00188] In one embodiment, the connector assemblies 862, 864 extend through a hole in the environmental chamber 823. Further, the fluid bearing housing 892, the fluid bearing source 894, the connector heat exchanger 896, and the housing circulation system 898 are positioned outside of the environmental chamber 823. In this design, the fluid bearing source 894 is used to (i) create a rotary air bearing 894A and sliding seal in an upper region between the fluid bearing housing 892 and the first connector assembly 862; and (ii) create a bearing gas film 894B in a lower region between the fluid bearing housing 892 and the first connector assembly 862.

[00189] In one example, the bearing housing 892 can include (i) one or more upper vacuum ports 892A (only one is shown); (ii) one or more intermediate, atmospheric ports 892B (only one is shown) that are at atmospheric pressure; and (iii) one or more lower, high pressure ports 892C (only one is shown). With this design, the bearing source 894 can (i) create a vacuum in the upper vacuum ports 892A; and (ii) supply a gas to the high pressure port 892C to create a high pressure gas film 894B between the fluid bearing housing 892 and the first connector assembly 862.

[00190] With this design, heat from the first connector assembly 862 is conducted via the bearing gas film 894B to the fluid bearing housing 892. Further, the connector heat exchanger 896 is attached to and thermally connected to the fluid bearing housing 892.

[00191] The housing circulation system 898 can circulate a frame circulation fluid 898A

(illustrated with small squares) through the connector heat exchanger 896 to control the temperature of and/or remove heat from the first connector assembly 862. In this design, the connector heat exchanger 896 can define a separate fluid passageway (not shown). Alternatively, the connector heat exchanger 896 can be integrated into the fluid bearing housing 892 with the fluid passageway(s) formed within the fluid bearing housing 892. The heat exchanger 896 can include materials with relatively high thermal conductivity. Further, the housing circulation system 898 includes one or more pumps, reservoirs, chillers, etc., to control the flow rate and/or temperature of the circulation fluid 898A.

[00192] One or more conduits 898B can connect the housing circulation system 898 in fluid communication with the connector heat exchanger 896.

[00193] It should be noted that the housing circulation system 898 can optionally include one or more temperature sensors 898C that monitor the temperature of the connector heat exchanger 896, the bearing housing 892, and/or the first connector assembly 862, or other locations. These temperature sensor(s) 898C allow for closed loop control of the housing circulation system 898. Alternatively, instead of the connector heat exchanger 896, a circulation fluid channel can be provided in the bearing housing 892 itself. In such design, the housing circulation system 898 flows the circulation fluid 898A in the bearing housing 892 and remove the heat more directly from the first connector assembly 862 via the bearing gas film 894B. Still alternatively or additionally, by controlling the temperature of the bearing gas supplied from fluid bearing source 894 to the bearing housing 892 via the port 892B which creates the bearing gas film 894B, the heat of the first connector assembly 862 can be removed by the bearing gas film 894B. The fluid bearing source 894 may comprise a temperature controller for the bearing gas, or the housing circulation system 898 may control the temperature of the bearing gas.

[00194] Additionally, optionally, a portion of the first connector assembly 862 can be made of a material having a relatively low thermal conductivity, and can function as a thermal insulator.

[00195] In certain implementations, the heat from one or both of the connector assemblies 862 and 864 may be removed by using the gas supplied from port 892C, which creates the high pressure gas film 894B between the fluid bearing housing 892 and

the first connector assembly 862.

[00196] In alternative such implementations, the heat being removed by using the gas supplied from port 892C may be conducted with the connector temperature control system 890 or instead of the connector temperature control system 890.

[00197] Figure 9A is a simplified cut-away view of an object 911 and a portion of a three-dimensional processing machine 910 with yet another implementation of the material bed assembly 914, the assembly mover assembly 925 that moves the material bed assembly 914, and the mover connector assembly 960 that physically connects the assembly mover assembly 925 to the material bed assembly 914. It should be noted that many of the other components of the processing machine 910 have been omitted for clarity. Further, a portion of the environmental chamber 923 is illustrated in Figure 9A that separates the material bed assembly 914 from the assembly mover assembly 925. The design of these components can be varied pursuant to the teachings provided herein.

[00198] In one, non-exclusive implementation, the material bed assembly 914 includes a single, support frame 926 that supports the object 911 while it is being built. In Figure 9A, a single object 911 is illustrated on the support frame 926. Alternatively, the support frame 926 can be designed to support multiple objects (not shown) simultaneously while being built. Additionally or alternatively, the support frame 926 can be designed to include one or more build platform assemblies 828 (illustrated in Figure 8) that can be used to support the object(s) 911.

[00199] It should be noted that the material bed assembly 914 can be designed to include multiple support frames as described above in the previous implementations.

[00200] The assembly mover assembly 925 can be controlled to precisely move the material bed assembly 914. The design of the assembly mover assembly 925 can be varied to achieve the desired movement requirements of the support frame 926. In one non-exclusive implementation, the assembly mover assembly 925 can be controlled to selectively (i) rotate the support frame 926 about the central axis 926C; and (ii) move the support frame 926 linearly along the central axis 926C. In the non-exclusive implementation of Figure 9A, the assembly mover assembly 925 includes (i) a first actuator 925A that rotates the support frame 926 about the central axis 926C; (ii) an actuator frame 925D; and (iii) a second actuator assembly 925B that moves the actuator

frame 925D, the first actuator 925A, and the support frame 926 linearly along the central axis 926C.

[00201] The first actuator 925A can include a rotary motor that is coupled to the actuator frame 925D and the mover connector assembly 960.

[00202] The actuator frame 925D is rigid and supports a portion of the first actuator 925A and the second actuator assembly 925B. In one non-exclusive implementation, the actuator frame 925D is annular disk shaped. However, other shapes are possible.

[00203] The second actuator assembly 925B can include (i) a first rotary motor 925Ba that is attached to the environmental chamber 923, (ii) a second rotary motor 925Bb that is attached to the environmental chamber 923, (iii) a first, internally threaded member 925Bc that is attached to the actuator frame 925D, and (iv) a second, internally threaded member 925Bd that is attached to the actuator frame 925D. These components cooperate to move the actuator frame 925D, the first actuator 925A, and the support frame 926 linearly. For example, each rotary motor 925Ba, 925Bb can be a worm gear actuator including (i) a motor that is attached to the environmental chamber 923, and (ii) a threaded shaft 925Be. With this design, (i) the threaded shaft 925Be of the first rotary motor 925Ba engages the first threaded member 925Bc; and (ii) the threaded shaft 925Be of the second rotary motor 925Bb engages the second threaded member 925Bd. With this design, rotation of the threaded shafts 925Be causes the actuator frame 925D to move linearly. However, other types of actuators can be utilized.

[00204] The mover connector assembly 960 physically couples the assembly mover assembly 925 to the material bed assembly 914. As a non-exclusive implementation, the mover connector assembly 960 can include (i) a connector assembly 962 (e.g., a drive shaft) that mechanically connects the assembly mover assembly 925 to the material bed assembly 914 through the environmental chamber 923; (ii) a connector housing 963a; and (iii) a mechanical bellows 963b. The design of each of these components can be varied.

[00205] The connector assembly 962 mechanically connects the assembly mover assembly 925 to the material bed assembly 914 through the environmental chamber 923. For example, the connector assembly 962 can be a rigid shaft.

[00206] The connector housing 963a encircles a portion of the drive shaft 962, and is

used to guide the movement of the drive shaft 962. For example, the connector housing 963a can have an annular passageway that receives the drive shaft 962. Moreover, the connector housing 963a can be secured to the environmental chamber 923. In this design, the drive shaft 962 is spaced apart from the connector housing 963a by a bearing gap 965.

[00207] The mechanical bellows 963b seals the connector housing 963a to the actuator frame 925D while allowing the actuator frame 925D to move linearly relative to the connector housing 963a.

[00208] In one implementation, the mover connector assembly 960 additionally includes a fluid bearing source 994 that is used to create a fluid bearing 994A (“bearing assembly”) and a sliding seal between the connector housing 963a and the drive shaft 962 (in the bearing gap 965) similar to the design described above in reference with Figure 8. In this design, the connector housing 963a can also be referred to a “fluid bearing housing” and can include (i) one or more upper vacuum ports; (ii) one or more intermediate, atmospheric ports that are at atmospheric pressure; and (iii) one or more lower, high pressure ports. With this design, the bearing source 994 can (i) create a vacuum in the upper vacuum ports; and (ii) supply a gas to the high pressure port to create a high pressure gas film between the connector housing 963a and the connector assembly 962. The bearing source 994 can be similar to the corresponding assembly described with reference to Figure 8.

[00209] With the present design, heat from the drive shaft 962 is conducted via the bearing gas film to the connector housing 963a. Additionally, a housing circulation system 998 can circulate a frame circulation fluid through or near the connector housing 963a to control the temperature of and/or remove heat from the connector housing 963a. The housing circulation system 998 can be similar to the corresponding assembly described with reference to Figure 8. With this design, a temperature of the mover connector assembly 960 can be actively controlled. Stated in another fashion, the fluid bearings 994A can also be utilized for actively controlling the temperature of and/or removing heat from the mover connector assembly 960. As such, the fluid bearings 994A can further function as and/or be referred to as a heat dissipation assembly.

[00210] In the implementation shown in Figure 9A, the problem of supporting the

frictionless rotation of a rotating material bed assembly 914 of a processing machine 910, such as a metal 3-D printer, while still allowing for precise vertical translation of the material bed assembly 914 is solved by using rotary fluid (e.g., air) bearings 994A that provide near-frictionless motion in both rotation and translation.

[00211] In Figure 9A, the material bed assembly 914, which carries one or more objects 911, sits on the top of the mechanical assembly. In some, non-exclusive applications, the material bed assembly 914 rotates at approximately 3.5 RPM counter-clockwise continuously. Further, in certain non-exclusive implementations, for every full rotation of the material bed assembly 914, the material bed assembly 914 can be lowered approximately 100 microns to accommodate a new material layer for the 3-D printed object. Because the material bed assembly 914 is typically operated at very high temperatures (e.g., in excess of 500 C) and in a vacuum environment, the actuators of the assembly mover assembly 925 driving the motion of the material bed assembly 914 are placed relatively far away from the material bed assembly 914 and the object 911. As shown in Figure 9A, the actuators of the assembly mover assembly 925 are placed far below the material bed assembly 914 itself. In this implementation, the motion from the actuators is coupled to the material bed assembly 914 via the mover connector assembly 960 provided in the form of a stiff, rotating shaft 962. With such design, the shaft 962 of the mover connector assembly 960 couples both rotation and translation.

[00212] In the implementation of Figure 9A, the rotating material bed assembly 914 can resemble an “inverted pendulum,” where the center of mass of the support frame 926 is far above the actuator 925 attachment locations. This configuration can pose several mechanical problems, including reductions to stiffness, accuracy, and dynamic performance. Accordingly, to combat this problem, with the present design, the fluid bearings 994A are placed close to a center of gravity of the support frame 926. These fluid bearings 994A can allow for both rotational and translational motion.

[00213] Another important aspect of the fluid bearings 994A in this implementation is that they will be used for the planar location constraint of the drive shaft 962 of the mover connector assembly 960. Therefore, the center of rotation and global positioning of the entire material bed assembly 914 will depend on the location of the fluid bearings 994A, making the fluid bearings 994A even more critically important for the performance of the

processing machine 910.

[00214] With this design, the fluid bearings 994A provide near frictionless prismatic and rotational motion across small air gaps. This is ideal for the 3-D printing application where high precision and accuracy are required for optimizing both throughput and build quality. Furthermore, the fluid bearings 994A are advantageous in this application because in nominal use cases, the fluid bearings 994A will have zero wear. This minimizes any inconsistent performances or “drift” that may occur over the lifetime of the processing machine 910 that may introduce errors into the building of the object. This importance is further magnified by the fact that the fluid bearings 994A will be used to consistently position the entire stage in the XY plane. Thus, the use of the fluid bearings 994A can be preferred over a plain bushing, which operates via physical contact between two solid pieces, and would not be as reliable as a fluid bearing. Stated in another manner, plain bushings may not be a good candidate because they generate more friction and will wear over time, leaving residue or reducing position accuracy of the shaft 962 of the mover connector assembly 960. Furthermore, the fluid bearings 994A are naturally more compact than other alternatives, which makes their use ideal in a 3-D printing application where size and space constraints are always a concern.

[00215] It is appreciated that other bearing alternatives, such as ball or roller bearings, would also be possible. The fluid bearings 994A also allow for both rotational motion and translational motion along the bearing with near-zero friction. Conventional rotary bearings such as ball or roller bearings typically only allow for only rotational motion and restrict translational motion of the shaft.

[00216] Figure 9B is an enlarged view of a portion of the processing machine 910 of Figure 9A including a portion of the material bed assembly 914 and a portion of the environmental chamber 923. More particularly, Figure 9B illustrates an enlarged view of a portion of the support frame 926, the mover connector assembly 960 and the fluid bearing 994A.

[00217] Figure 9C is an enlarged view of the portion of the processing machine 910 of Figure 9B including a portion of the material bed assembly 914 and a portion of the environmental chamber 923. Further, Figure 9C illustrates an enlarged view of a portion of the support frame 926, the mover connector assembly 960 and the fluid bearing 994A

(illustrated with arrows). Further, Figure 9C illustrates that heat 999 (illustrated with arrows) which is transferred from the support frame 926 to the drive shaft 962 is transferred (e.g., by convection) via the fluid bearing 994A to the connector housing 963a. Subsequently, the temperature of connector housing 963a can be actively controlled (e.g., cooled). For example, the housing circulation system 998 (illustrated in Figure 9A) can direct a circulation fluid near or through the connector housing 963a to actively control the temperature of the connector housing 963a, the shaft 962, and the support frame 926.

[00218] Stated in another fashion, Figure 9C illustrates fluid (e.g., air) bearing 994A cooling for the high temperature shaft 962 of a rotary support frame 926 of a processing machine 910 such as a metal 3-D printer system. As described herein, the problem of preventing heat from the rotary support frame 926 from damaging sensitive components connected to the support frame 926 (such as actuators and sensors) is solved by using the fluid from the rotary fluid bearings 994A to cool the shaft 962 that connects the hot support frame 926 to the sensitive components.

[00219] Additionally, in this implementation, the drive shaft 962 of the mover connector assembly 960 is supported via the fluid bearings 994A that sit between the hot rotary support frame 926 and the actuators/sensitive components. The drive shaft 962 is long and narrow and will provide a naturally high thermal resistance path for heat, thus greatly reducing the danger of heat damaging the sensitive components.

[00220] However, the rotating support frame 926 can be in excess of five hundred degrees Celsius and the mover connector assembly 960 can still transfer heat to the actuators and sensors below at steady-state due to high operating temperatures. Furthermore, because the system is nominally in vacuum, the heat cannot be typically convected or conducted away from the shaft 962 of the mover connector assembly 960 before it reaches the motors and sensors. This can further exacerbate the heat transfer problem.

[00221] As provided herein, in order to combat this issue, the fluid bearings 994A can be used to convect and conduct heat away from the shaft 962 of the mover connector assembly 960. Because the fluid bearings 994A sit between the hot support frame 926 and the sensitive components, heat must first reach the fluid bearings 994A before it can reach the sensitive components. This allows the fluid coming from the fluid bearings 994A

to effectively “cool” the shaft 962 of the mover connector assembly 960 and provide a heat sink for any extra heat that may damage the sensitive components below.

[00222] In this implementation, the connector housing 962a can be cooled (e.g., water cooled) to pull the heat away that is convected from the fluid bearings 994A. With such design, heat can be transferred out via the connector housing 962a before reaching the sensitive components below. Additionally, removing the heat in such manner also helps to ensure that the heat also does not damage the fluid bearings 994A.

[00223] In certain designs, the fluid bearings 994A can be better than a standard roller bearing or plain bushing because the main heat transfer method will be convection. If another bearing is used where the bearing is provided via contact between two solids, then conduction becomes the primary mode of heat transfer.

[00224] It should also be noted that cooling the shaft 962 of the mover connector assembly 960 via the fluid bearings 994A will minimize effects due to thermal expansion of the shaft 962. This will further help inhibit position error of the material bed assembly 914 and also minimize danger of binding due to radial thermal expansion.

[00225] Figure 10 is a simplified cut-away view of a portion of still another implementation of the processing machine 1010 with an object 1011. More specifically, Figure 10 illustrates the material bed assembly 1014, the mover connector assembly 1060, and a portion of the environmental chamber 1023. It should be noted that the processing machine 1010 is similar to the corresponding components described above, and that many of the other components of the processing machine 1010 have been omitted from Figure 10 for clarity, such as the assembly mover assembly.

[00226] In Figure 10, the material bed assembly 1014 includes a single, support frame 1026 that supports the object 1011 while it is being built. Alternatively, the support frame 1026 can be designed to support multiple objects (not shown) simultaneously while being built. Additionally or alternatively, the support frame 1026 can be designed to include one or more build platform assemblies 828 (illustrated in Figure 8) that can be used to support the object(s) 1011. Further, the material bed assembly 1014 can be designed to include multiple support frames as illustrated in some of the previously described implementations.

[00227] In Figure 10, the assembly mover assembly can be controlled to selectively (i)

rotate the support frame 1026 about the central axis 1026C; and (ii) move the support frame 1026 linearly along the central axis 1026C. Alternatively, the assembly mover assembly can be designed to move the support frame 1026 in a different fashion.

[00228] The mover connector assembly 1060 physically couples the assembly mover assembly to the material bed assembly 1014. As a non-exclusive implementation, the mover connector assembly 1060 can include (i) a connector assembly 1062 (e.g., a drive shaft) that mechanically connects the assembly mover assembly to the material bed assembly 1014 through the environmental chamber 1023; and (ii) a connector housing 1063. The design of each of these components can be varied. These components can be similar to the corresponding components described above.

[00229] The connector housing 1063 encircles a portion of the connector assembly 1062, and is used to guide the movement of the connector assembly 1062. For example, the connector housing 1063 can have an annular passageway that receives the connector assembly 1062. Moreover, the connector housing 1063 can be secured to the environmental chamber 1023. Further, in this design, the drive shaft 1062 is spaced apart from the connector housing 1063 by a bearing gap 1065.

[00230] In one implementation, the mover connector assembly 1060 additionally includes a fluid bearing source 1094 (illustrated as a box) that is used to create a fluid bearing 1094A (illustrated with arrows) and a sliding seal between the connector housing 1063 and the drive shaft 1062 similar to the design described above in reference with Figures 9A-9C. It is appreciated that other bearing alternatives can be used in the mover connector assembly 1060, such as one or more ball or roller bearings. Any of these bearings can be referred to generically as "bearing assembly".

[00231] Unfortunately, excess powder 12 (illustrated as small circles) from the three-dimensional printing process in the environmental chamber 1023 can migrate into the bearing gap 1065 between the drive shaft and the connector housing 1063, and into the bearing assembly 1094A. In certain designs, the main location where material 12 can enter the bearing gap 1065 is where the connector housing 1063 is open in the environmental chamber 1123.

[00232] The powder 12 in the bearing assembly 1094A can damage the bearing assembly 1094A, jam the drive shaft 1062 to the connector housing 1063, and/or cause

wear in the drive shaft 1062 and the connector housing 1063. Stated differently, the bearing gap 1065 is nominally small and may be on the order of fifty to one hundred microns for vacuum conductance purposes. As a result, the material 12, which can also be approximately the same size, could eventually clog the bearing gap 1065, causing either significant scratching and damage of the components 1062, 1063, or a jam that will stop motion of the entire connector assembly 1062.

[00233] A number of alternative designs are provided herein that inhibit the material 12 from entering the bearing gap 1065 and the bearing assembly 1094A. In certain implementations, a material inhibitor 1002 is utilized. The design of the material inhibitor 1002 can be varied pursuant to the teachings provided herein. Further, a number of different material inhibitors 1002 are provided herein. It should be noted that these material inhibitors 1002 can be used individually or jointly.

[00234] Figure 10 is a simplified illustration of a first, possible material inhibitor 1002. In this design, the material inhibitor 1002 is a material shield assembly that includes a baffle assembly that creates a difficult path for material 12 to enter the bearing gap 1065. In the simplified design of Figure 10, the baffle assembly 1002 includes an annular shaped, first baffle component 1003 that is secured to (and moves with) the drive shaft 1062, and an annular shaped second baffle component 1004 that is coupled to the connector housing 1063 and/or the environmental chamber 1023. With this design, the first baffle component 1003 moves relative to the second baffle component 1004, the baffle components 1003, 1004 are spaced apart, and the baffle components 1003, 1004 cooperate to create a labyrinth-like path that makes it excessively difficult for loose material 12 to enter the bearing gap 1065.

[00235] It should be noted that in the implementation of Figure 10, the baffle assembly 1002 includes a single, first baffle component 1003 and a single, second baffle component 1004. Alternatively, the baffle assembly 1002 can be designed to include more than one, spaced apart first baffle components 1003, and/or more than one, spaced apart second baffle component 1004.

[00236] Figure 11 is a simplified cut-away view of a portion of still another implementation of the processing machine 1110 with an object 1111. More specifically, Figure 11 illustrates the material bed assembly 1114, the mover connector assembly

1160, and a portion of the environmental chamber 1123. It should be noted that the processing machine 1110 of Figure 11 is similar to the design illustrated in Figure 10, except the material inhibitor 1102 is different.

[00237] In Figure 11, the mover connector assembly 1160 can again include a fluid bearing source 1194 (illustrated as a box) that is used to create a fluid bearing 1194A (illustrated with arrows) and a sliding seal between the connector housing 1163 and the drive shaft 1162. It is appreciated that other bearing alternatives can be used in the mover connector assembly 1160, such as one or more ball or roller bearings. Any of these bearings can be referred to generically as “bearing assembly”.

[00238] As discussed above, excess powder 12 (illustrated as small circles) from the three-dimensional printing process in the environmental chamber 1123 can migrate into the bearing gap 1165 between the drive shaft 1162 and the connector housing 1063, and into the bearing assembly 1194A.

[00239] Figure 11 is a simplified illustration of another, possible material inhibitor 1102. In this design, the material inhibitor 1102 is a material shield assembly that includes a wiper assembly (e.g., a brush or wiper) that sweeps away any loose powder 12 that may have built up on the drive shaft 1162. In the non-exclusive implementation of Figure 11, the wiper assembly 1102 extends between (i) the drive shaft 1162, and (ii) the connector housing 1163 and/or the environmental chamber 1123. In this design, the wiper assembly 1102 is a tapered, annular shaped ring having a fixed, first end 1102a that is secured to the environmental chamber 1123, and a second end 1102b that encircles the drive shaft 1162. With this design, the drive shaft 1162 moves relative to the wiper assembly 1102, and the wiper assembly 1102 creates a difficult path for material 12 to enter the bearing gap 1165.

[00240] Alternatively, the second end 1102b can be secured to the drive shaft 1162, and the first end 1102a can move relative to the connector housing 1163 and/or the environmental chamber 1123.

[00241] In Figure 11, the wiper assembly 1102 includes a single, wiper. Alternatively, the wiper assembly 1102 can be designed to include more than one, spaced apart, wipers.

[00242] Figure 12 is a simplified cut-away view of a portion of still another

implementation of the processing machine 1210 with an object 1211. More specifically, Figure 12 illustrates the material bed assembly 1214, the mover connector assembly 1260, and a portion of the environmental chamber 1223. It should be noted that the processing machine 1210 of Figure 12 is similar to the design illustrated in Figure 10, except the material inhibitor 1202 is different.

[00243] In Figure 12, the mover connector assembly 1260 can again include a fluid bearing source 1294 (illustrated as a box) that is used to create a fluid bearing 1294A (illustrated with arrows) and a sliding seal between the connector housing 1263 and the drive shaft 1262. It is appreciated that other bearing alternatives can be used in the mover connector assembly 1260, such as one or more ball or roller bearings.

[00244] As discussed above, excess powder 12 (illustrated as small circles) from the three-dimensional printing process in the environmental chamber 1223 can migrate into the bearing gap 1265 between the drive shaft 1262 and the connector housing 1263, and into the bearing assembly 1294A.

[00245] Figure 12 is a simplified illustration of another, possible material inhibitor 1202. In this design, the material inhibitor 1202 includes a magnet assembly that is positioned near the entrance to the bearing gap 1265 or at another location. This design can be used if the material 12 is influenced by a magnetic field (e.g., a metal), and the magnet assembly 1202 generates a magnetic field that pulls the material 12 powder away from the bearing gap 1265 before it can fall into the bearing gap 1265.

[00246] In Figure 12, the magnet assembly 1202 is an annular shaped magnet that is secured to the connector housing 1263 and/or the environmental chamber 1223, and that encircles the drive shaft 1262. In this design, the drive shaft 1262 moves relative to the magnet assembly 1202, and the magnet assembly 1202 attracts and retains any loose material 12.

[00247] In Figure 12, the magnet assembly 1202 includes a single, annular magnet. Alternatively, the magnet assembly 1202 can be designed to include multiple, spaced apart, concentric, annular magnets. Still alternatively, the annular shaped magnet assembly 1202 can be replaced with a plurality of magnets that cooperate to encircle the drive shaft 1262. The magnet assembly 1202 used to protect the fluid bearing can be actively generated via electromagnets, passively generated via permanent magnets, or

both. For instance, for some powders 12 that are highly magnetic, a lower magnetic field presence may be enough. Alternatively, with very lightly magnetic steels, a stronger field might be desired. In certain implementations, for example, the control system 24 (illustrated in Figure 1A) can control the magnet assembly 1202 so the field could be electronically strengthened or weakened to account for the characteristics of the material 12. In certain implementations, one or more magnetic shields 1206 can be positioned near the magnet assembly 1202 to inhibit the influence of the magnetic field on the energy beam 22A (illustrated in Figure 1A). In Figure 12, the design includes a single, annular shaped magnetic shield 1206 that is secured to the shaft 1262 and that is spaced apart from the material inhibitor 1202. However other designs of the magnetic shield 1206 are possible.

[00248] Figure 13 is a simplified cut-away view of a portion of still another implementation of the processing machine 1310 with an object 1311. More specifically, Figure 13 illustrates the material bed assembly 1314, the mover connector assembly 1360, and a portion of the environmental chamber 1323. It should be noted that the processing machine 1310 of Figure 13 is somewhat similar to the design illustrated in Figure 10, except the material inhibitor 1302 is different.

[00249] In Figure 13, the mover connector assembly 1360 can again include a fluid bearing source 1394 (illustrated as a box) that is used to create a fluid bearing 1394A (illustrated with arrows) and a sliding seal between the connector housing 1363 and the drive shaft 1362. It is appreciated that other bearing alternatives can be used in the mover connector assembly 1360, such as one or more ball or roller bearings.

[00250] As discussed above, excess powder 12 (illustrated as small circles) from the three-dimensional printing process in the environmental chamber 1323 can migrate into the bearing gap 1365 between the drive shaft 1362 and the connector housing 1363, and into the bearing assembly 1394A.

[00251] Figure 13 is a simplified illustration of another, possible material inhibitor 1302. In this design, the material inhibitor 1302 is another material shield assembly that includes a baffle assembly that creates a difficult path (without physical contact) for material 12 to enter the bearing gap 1365. In the simplified design of Figure 13, the baffle assembly 1302 includes (i) a first baffle component 1303 that is secured to (and/or formed into) the

drive shaft 1362 and moves with the drive shaft 1362, and (ii) a second baffle component 1304 that is coupled to the connector housing 1363 and/or the environmental chamber 1323. For example, (i) the first baffle component 1303 can include one or more spaced apart annular shaped rings (protruding flanges) 1303a that extend away from the drive shaft 1362; and (ii) the second baffle component 1304 includes an annular frame 1304a and one or more annular fingers 1304b that cantilever inward from the annular frame 1304a. The number of rings 1303a and fingers 1304b can be varied. In the non-exclusive example of Figure 13, the material inhibitor 1302 includes three spaced apart rings 1303a and four spaced apart fingers 1304b that are interspersed. However, other designs are possible.

[00252] With the design of Figure 13, the first baffle component 1303 moves relative to the second baffle component 1304, the baffle components 1303, 1304 are spaced apart, and the baffle components 1303, 1304 cooperate to create a labyrinth-like path that makes it excessively difficult for loose material 12 to enter the bearing gap 1365.

[00253] It should be noted that other designs are possible. For example, the labyrinth features can be machined into the shaft 1062 as a series of grooves.

[00254] In Figure 13, the rings 1303a and fingers 1304b extend generally perpendicular to the shaft 1062. Alternatively, the rings 1303a and fingers 1304b could be oriented diagonally to the shaft 1062.

[00255] Additionally, it should be noted that in certain designs, regular maintenance may be required to inhibit clogging of the powder 12. In this regard, the designs in Figures 10-13 must be replaceable, cleanable, and/or interchangeable.

[00256] Additionally, and optionally, the processing machine 1310 can include a material detector assembly 1306 (illustrated as a box) to determine when powder 12 has entered (or is about to enter) the gap 1365 so as to inhibit permanent or expensive damage to the machine. The components of fluid bearings 1394A are very expensive and can be difficult to repair/remove/replace. Therefore, the material detector assembly 1306 can indicate when service is necessary prior to failure of the system. For example, the material detector assembly 1306 can include one or more sensors, and one or more sensor(s) can be ultrasonic, optical, magnetic, and/or capacitive, as non-exclusive examples that determine when material inhibitor 1302 is getting plugged. The material

detector assembly 1306 can be implemented in any of the designs provided herein.

[00257] In certain implementations, a labyrinth gaps 1302a between the rings 1303a and the fingers 1304b can be designed to be smaller than the bearing gap 1365. With this design, the labyrinth will clog before the fluid bearing 1394A, rendering the machine 1310 inoperable prior to damage to more expensive parts that form the fluid bearing 1394A.

[00258] It should be noted that one or more the material inhibitors 1002, 1102, 1202, 1302 in Figures 10-13 can be used individually or in combination with each other.

[00259] Additionally, it should be noted that the implementations described in reference to Figures 4 to 13 above are also able to be implemented in the material bed assembly 14, 214, 314 described in reference to Figures 1A to 3. For example, the connectors 432A or flexures 566, 666 in Figures 4 to 6 can be used as the thermal insulator 46, 246, 346. Further, the implementations explained above is not only applicable to a processing machine having a rotatable material bed system, but also can be utilized in a processing machine having a material bed that is not rotating but only moving vertically.

[00260] The invention can be implemented in numerous ways, including as a process; an apparatus; a system; a composition of matter; a computer program product embodied on a computer readable storage medium; and/or a processor, such as a processor configured to execute instructions stored on and/or provided by a memory coupled to the processor. In this specification, these implementations, or any other form that the invention may take, may be referred to as techniques. In general, the order of the steps of disclosed processes may be altered within the scope of the invention. Unless stated otherwise, a component such as a processor or a memory described as being configured to perform a task may be implemented as a general component that is temporarily configured to perform the task at a given time or a specific component that is manufactured to perform the task. As used herein, the term 'processor' refers to one or more devices, circuits, and/or processing cores configured to process data, such as computer program instructions.

[00261] It is understood that although a number of different embodiments of the processing machine have been illustrated and described herein, one or more features of any one embodiment can be combined with one or more features of one or more of the

other embodiments, provided that such combination satisfies the intent of the present disclosure.

[00262] While a number of exemplary aspects and embodiments of the processing machine have been discussed above, those of skill in the art will recognize certain modifications, permutations, additions and sub-combinations thereof. It is therefore intended that the following appended claims and claims hereafter introduced are interpreted to include all such modifications, permutations, additions and sub-combinations as are within their true spirit and scope.

What is claimed is:

1. A processing machine for building a three-dimensional object from a material, the processing machine comprising:

a build platform that supports the material;

an energy system that directs an energy beam at the material on the build platform to selectively melt the material, wherein the energy beam directed at the material generates heat that is transferred to the build platform;

a first assembly that causes a movement of the build platform; and

a second assembly at least part of which is arranged opposite to the energy system with respect to the build platform, the second assembly reducing the amount of heat therethrough transferred from the build platform.

2. The processing machine of claim 1, wherein the first assembly includes a mover assembly that causes movement of the build platform at least in a direction intersecting to a support surface of the build platform that supports the material, and the second assembly includes a mover connector assembly that connects the mover assembly to the build platform.

3. The processing machine of claims 2, wherein the movement of the build platform includes a movement in a direction parallel to the support surface of the build platform.

4. The processing machine of any one of claim 1-3 wherein the first assembly is positioned opposite to the energy system with respect to the second assembly.

5. The processing machine of claim 2, wherein the mover connector assembly includes a heat dissipation assembly that reduces the amount of heat transferred from the build platform to the mover assembly.

6. The processing machine of claim 5 further comprising a heat spreader that is positioned between the build platform and the mover assembly, the heat spreader being configured to increase a contact area with the heat dissipation assembly.

7. The processing machine of claim 6 wherein the heat spreader has a thermal conductivity of greater than approximately ten Watts per meter-Kelvin.

8. The processing machine of any one of claims 6-7 wherein the heat spreader is formed from a material including at least one of copper, aluminum, silicon carbide, aluminum nitride, or pyrolytic graphite.

9. The processing machine of any one of claims 6-8 wherein the mover connector assembly includes a thermal insulator that reduces the amount of heat transferred from the build platform to the mover assembly.

10. The processing machine of claim 9 wherein the heat spreader is positioned between the thermal insulator and the build platform.

11. The processing machine of claim 9 wherein the heat spreader is positioned between the thermal insulator and the heat dissipation assembly.

12. The processing machine of any one of claims 5-11 wherein the heat dissipation assembly includes a flow channel, and a circulation system that directs a circulation fluid through the flow channel to reduce the amount of heat transferred from the build platform to the mover assembly.

13. The processing machine of claim 12 further comprising a sidewall, wherein the build platform is selectively movable within the sidewall.

14. The processing machine of claim 13 wherein the flow channel includes a step that is sized to fit within the sidewall.

15. The processing machine of any one of claims 5-11 wherein the heat dissipation assembly includes a chiller that reduces the amount of heat transferred from the build platform to the mover assembly.

16. The processing machine of claim 9 wherein the thermal insulator is made of a material having a thermal conductivity of less than fifty Watts per meter-Kelvin.

17. The processing machine of claim 16 further comprising a sidewall, wherein the build platform is selectively movable within the sidewall.

18. The processing machine of claim 17 wherein the thermal insulator is fixedly attached to the build platform; and wherein the thermal insulator is sized to fit within the sidewall and be selectively movable relative to the sidewall.

19. The processing machine of claim 1 further comprising a first support frame that supports the build platform; and a heat dissipation assembly that controls the temperature of the first support frame.

20. The processing machine of any one of claims 1-19 wherein the mover assembly moves the build platform linearly.

21. The processing machine of any one of claims 1-19 wherein the mover assembly rotates the build platform.

22. The processing machine of any one of claims 1-21 further comprising a first support frame that retains the build platform; a second mover assembly that causes relative movement between the build platform and the energy system; and a coupler assembly that couples the second mover assembly to the first support frame in a fashion that allows the first support frame to radially expand relative to second mover assembly.

23. The processing machine of claim 22 further comprising a second support frame; wherein the coupler assembly couples the first support frame to the second support frame; and wherein the second mover assembly is coupled to the second support frame.

24. The processing machine of claim 23 further comprising a circulation system that is configured to provide circulation fluid for at least one of the first support frame and the second support frame.

25. The processing machine of claim 24 wherein the circulation system is a liquid-based circulation system.

26. A processing machine for building a three-dimensional object from a material, the processing machine comprising:

a first support frame that supports the material;

an energy system that directs an energy beam at the material to selectively melt the material;

a mover assembly that causes relative movement between the first support frame and the energy system; and

a coupler assembly that couples the mover assembly to the first support frame in a fashion that allows the first support frame to thermally expand.

27. The processing machine of claim 26, wherein the mover assembly rotates the first support frame.

28. The processing machine of claim 26, wherein the coupler assembly defines a kinematic coupling.

29. The processing machine of claim 26 further comprising a second support frame; wherein the coupler assembly couples the first support frame to the second support frame; and wherein the mover assembly is coupled to the second support frame.

30. The processing machine of claim 29 wherein the coupler assembly couples the first support frame to the second support frame in a fashion that allows the first support frame to thermally expand relative to the second support frame.

31. The processing machine of claim 29 wherein the coupler assembly kinematically couples the first support frame to the second support frame.

32. The processing machine of claim 29 wherein the coupler assembly includes a plurality of spaced apart flexures that couple the first support frame to the second support frame.

33. The processing machine of claim 29 wherein the mover assembly rotates the first support frame and the second support frame.

34. The processing machine of claim 29 wherein the mover assembly vertically moves the first support frame and the second support frame.

35. The processing machine of claim 29 wherein the coupler assembly performs as a temperature buffer between the first support frame to the second support frame.

36. The processing machine of claim 26 wherein the mover assembly vertically moves the first support frame.

37. The processing machine of claim 26 wherein the first support frame includes a build platform, and the build platform supports the material.

38. The processing machine of claim 37 wherein the mover assembly rotates the build platform respect to the first support frame.

39. The processing machine of claim 26 wherein the coupler assembly includes three v-grooves and three hemispheres, the three v-grooves are radially arranged, the three hemispheres are radially arranged, and wherein the three v-grooves mate with the three hemispheres.

40. The processing machine of claim 26 wherein the coupler assembly inhibits gravity sag of the first support frame.

41. A processing machine for building a three-dimensional object from a material, the processing machine comprising:

- a material bed assembly that supports the material;

- an energy system that directs an energy beam at the material on the material bed assembly to selectively melt the material;

- an environmental chamber that encloses the material bed assembly;

- an assembly mover assembly that selectively moves at least a portion of the material bed assembly, the assembly mover assembly being positioned outside of the environmental chamber, the assembly mover assembly including a drive shaft that extends through the environmental chamber and that is connected to the material bed assembly; and

- a fluid bearing that seals the shaft to the environmental chamber, the fluid bearing allowing the shaft to mover relative to the environmental chamber.

42. The processing machine of claim 40, wherein the fluid flow from the fluid bearing flows out to the atmosphere.

43. The processing machine of any one of claims 41 and 42, wherein the fluid bearing includes a rough vacuum guard ring.

44. The processing machine of claim 43, wherein the fluid bearing includes an atmospheric vacuum guard ring.

45. The processing machine of claim 44, wherein the fluid bearing includes one or more additional, higher quality vacuum guard rings.

46. The processing machine of any one of claims 41-45, further comprising a bearing source, and wherein the bearing source controls the temperature and/or flow rate of the fluid to the fluid bearing to regulate the temperature of the drive shaft.

47. The processing machine of any one of claims 41-46, further comprising a mechanical bearing that supports at least a portion of the radial loads on the drive shaft.

48. The processing machine of claim 47, wherein the fluid bearing includes a rough vacuum guard ring.

49. The processing machine of any one of claims 47 and 48, wherein the fluid bearing includes an atmospheric vacuum guard ring.

50. The processing machine of any one of claims 47-49, wherein the fluid bearing includes one or more additional, higher quality vacuum guard rings.

51. The processing machine of claim 41, wherein the assembly mover assembly including an inner shaft that extends through the drive shaft and the environmental chamber, the inner shaft being connected to the material bed assembly.

52. The processing machine of claim 51, wherein the inner shaft and its driving mechanism are in the vacuum environment.

53. The processing machine of claim 51, further comprising an inner seal that seals the inner shaft to the drive shaft.

54. The processing machine of claim 41 further comprising a material inhibitor that inhibits material in the environmental chamber from entering the fluid bearing.

55. A processing machine for building a three-dimensional object from a material, the processing machine comprising:

a material bed assembly that supports the material;

an energy system that directs an energy beam at the material on the material bed assembly to selectively melt the material;

an environmental chamber that encloses the material bed assembly;

an assembly mover assembly that selectively moves at least a portion of the material bed assembly, the assembly mover assembly being positioned outside of the environmental chamber, the assembly mover assembly including (i) a drive shaft that extends through the environmental chamber and that is connected to the material bed assembly, (ii) a connector housing that is coupled to the environmental chamber, the shaft being spaced apart from the connector housing by a bearing gap; and (iii) a bearing assembly that connects the drive shaft to the connector housing while allowing the drive shaft to move relative to the connector housing; and

a material inhibitor that inhibits material in the environmental chamber from entering the bearing gap.

56. The processing machine of claim 55 wherein the material inhibitor includes a baffle assembly.

57. The processing machine of any one of claims 55 and 56 wherein the material inhibitor includes a wiper assembly.

58. The processing machine of any one of claims 55-57 wherein the material inhibitor includes a magnetic assembly.

59. A method for building a three-dimensional object from a material comprising:

- supporting the material with a build platform;

- directing an energy beam at the material on the build platform to selectively melt the material with an energy system, wherein the energy beam directed at the material generates heat that is transferred to the build platform;

- moving the build platform with a first assembly; and

- reducing the amount of heat transferred from the build platform through the first assembly with a second assembly, the second assembly at least partly being arranged opposite to the energy system with respect to the build platform.

60. A method for building a three-dimensional object from a material comprising:

- supporting the material with a first support frame;

- directing an energy beam at the material to selectively melt the material with an energy system;

- causing relative movement between the first support frame and the energy system with a mover assembly; and

- coupling the mover assembly to the first support frame in a fashion that allows the first support frame to thermally expand with a coupler assembly.

61. A method for building a three-dimensional object from a material comprising:

- supporting the material with a material bed assembly;

- directing an energy beam at the material on the material bed assembly to selectively melt the material with an energy system;

- enclosing the material bed assembly with an environmental chamber;

selectively moving at least a portion of the material bed assembly with an assembly mover assembly, the assembly mover assembly being positioned outside of the environmental chamber, the assembly mover assembly including a drive shaft that extends through the environmental chamber and that is connected to the material bed assembly; and

sealing the shaft to the environmental chamber with a fluid bearing, the fluid bearing allowing the shaft to move relative to the environmental chamber.

62. A method for building a three-dimensional object from a material comprising:

supporting the material with a material bed assembly;

directing an energy beam at the material on the material bed assembly to selectively melt the material with an energy system;

enclosing the material bed assembly with an environmental chamber;

selectively moving at least a portion of the material bed assembly with an assembly mover assembly, the assembly mover assembly being positioned outside of the environmental chamber, the assembly mover assembly including (i) a drive shaft that extends through the environmental chamber and that is connected to the material bed assembly, (ii) a connector housing that is coupled to the environmental chamber, the shaft being spaced apart from the connector housing by a bearing gap; and (iii) a bearing assembly that connects the drive shaft to the connector housing while allowing the drive shaft to move relative to the connector housing; and

inhibiting material in the environmental chamber from entering the bearing gap with a material inhibitor.

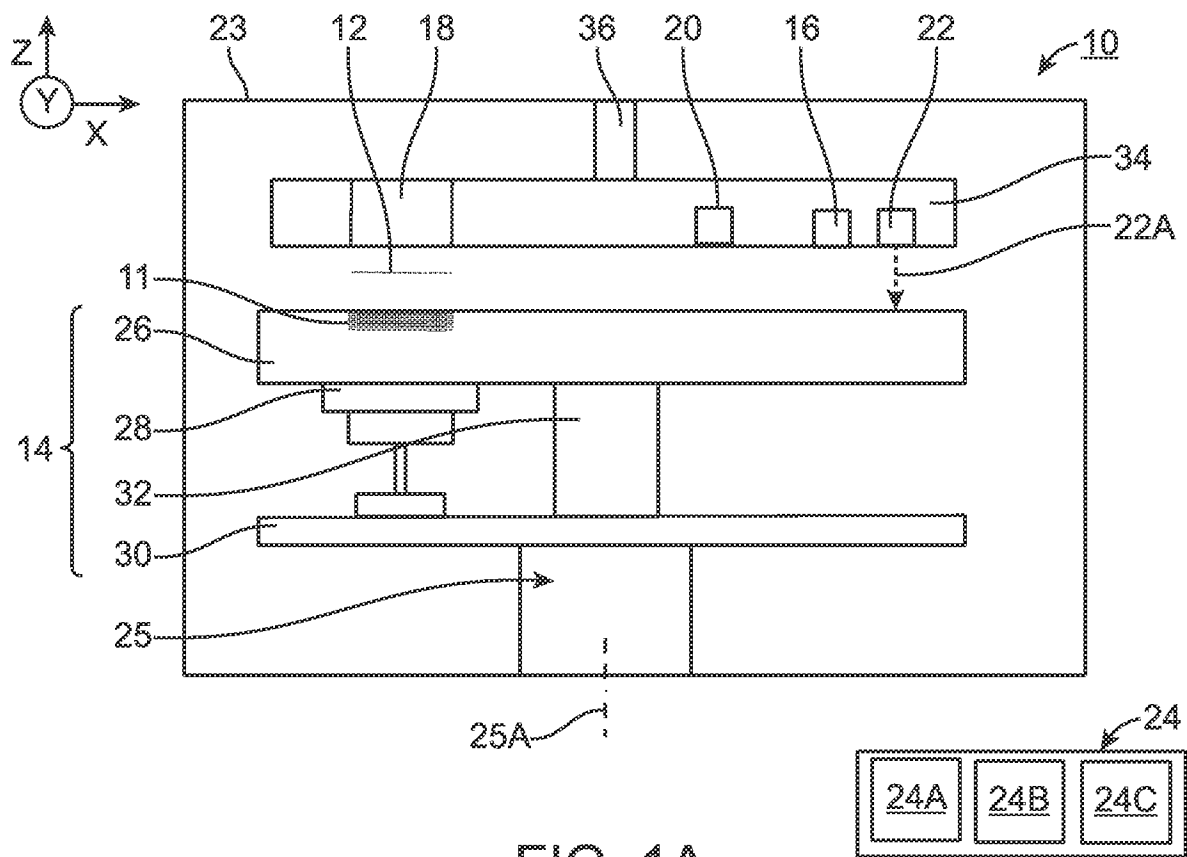


FIG. 1A

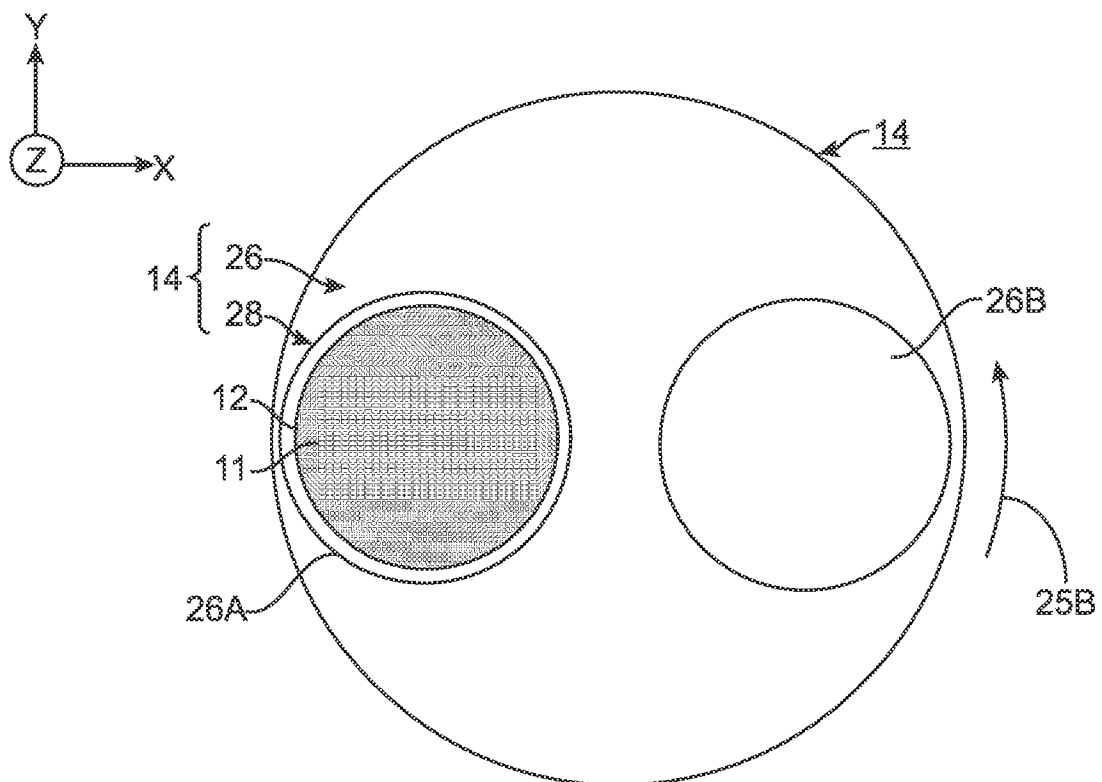


FIG. 1B

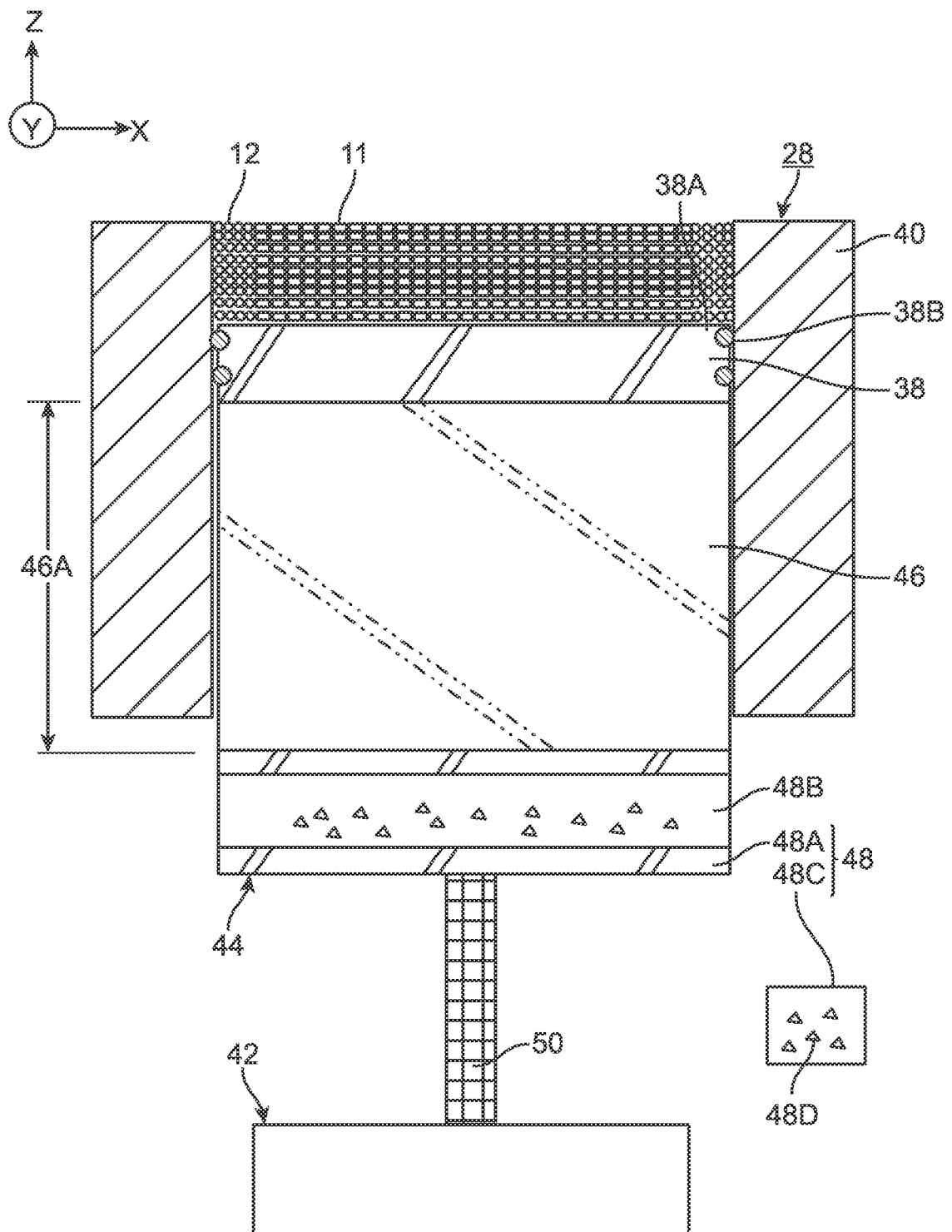


FIG. 1C

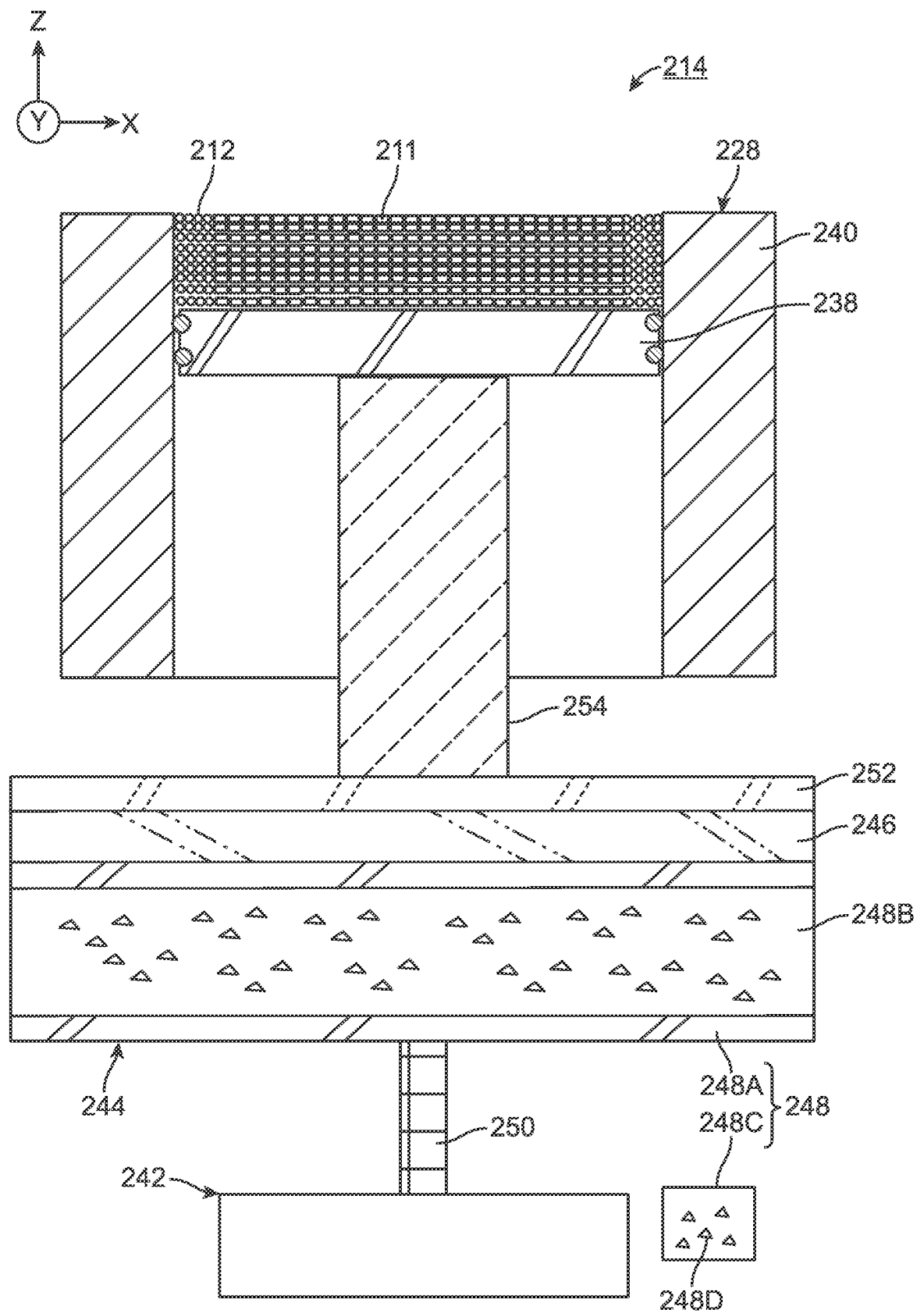


FIG. 2

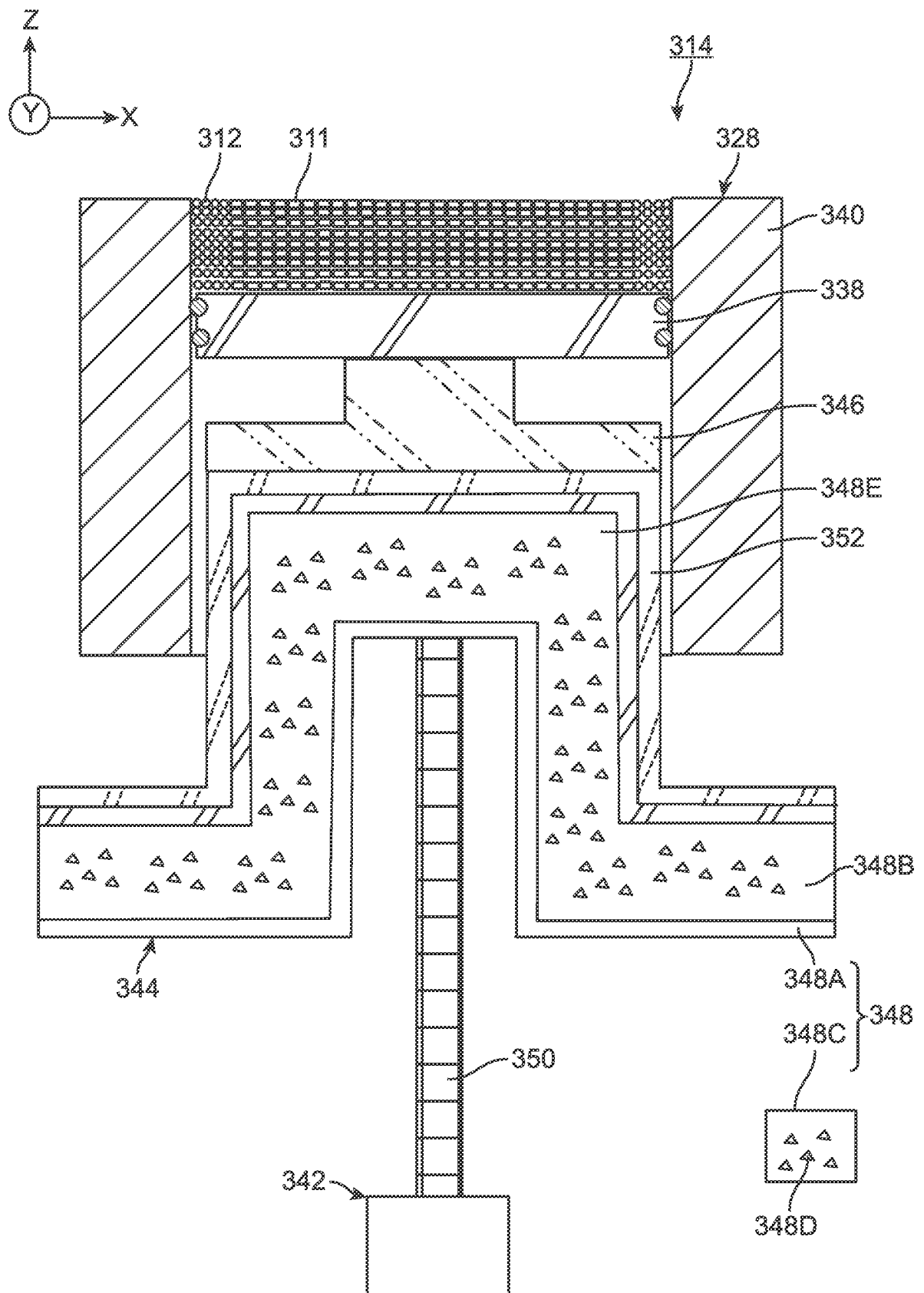


FIG. 3

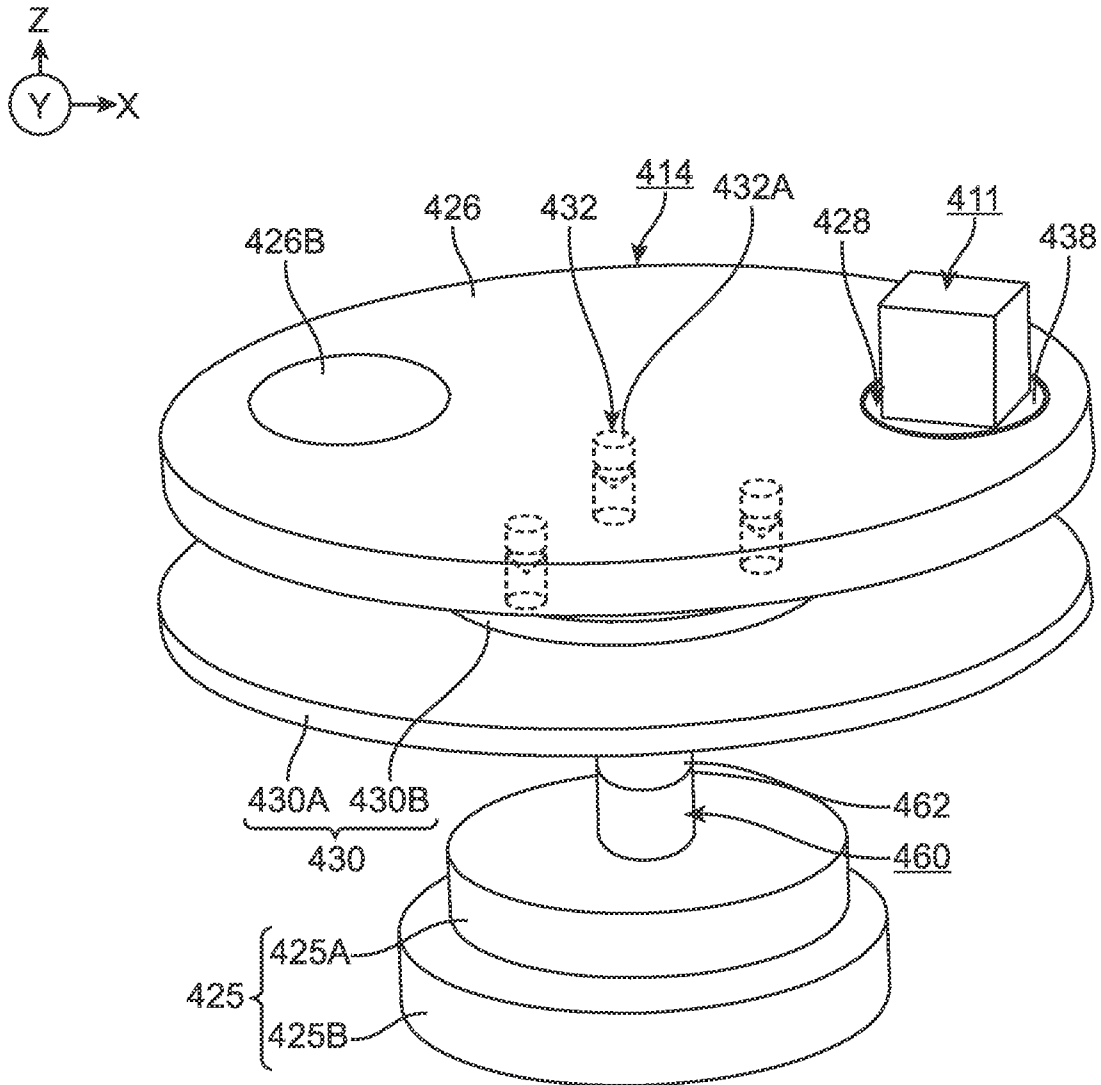


FIG. 4A

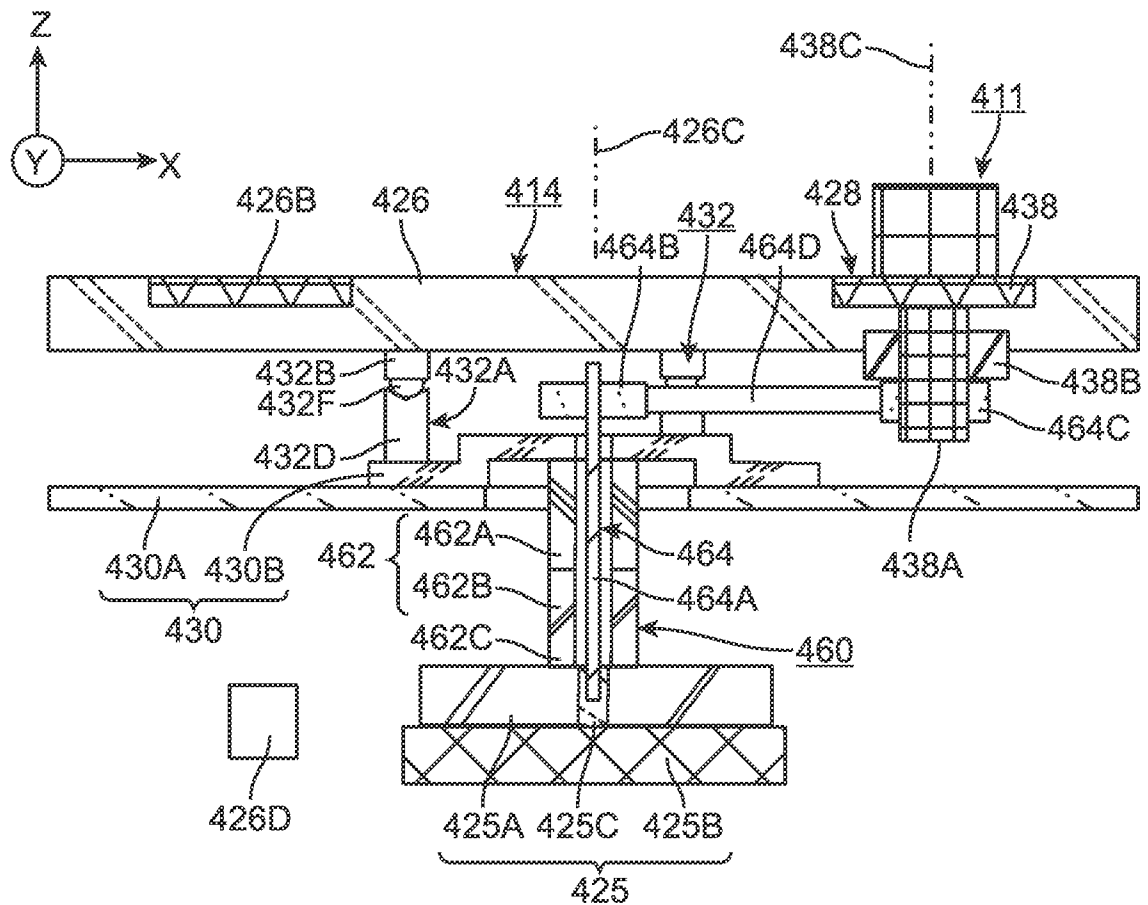


FIG. 4B

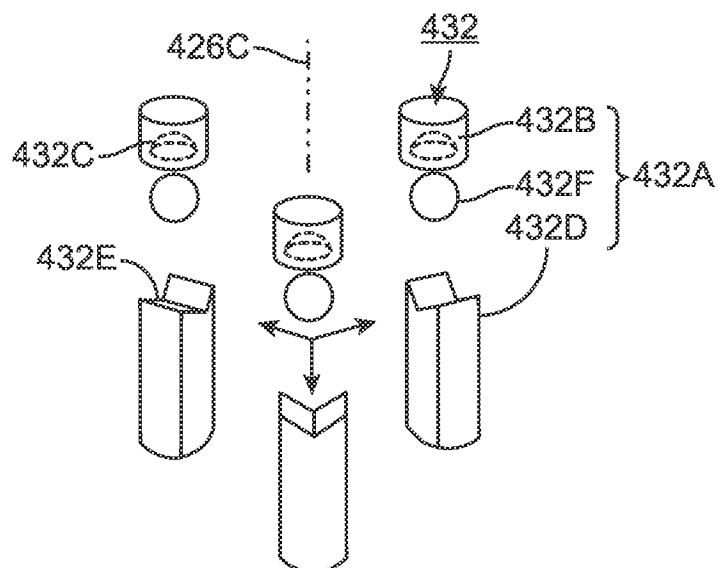


FIG. 4C

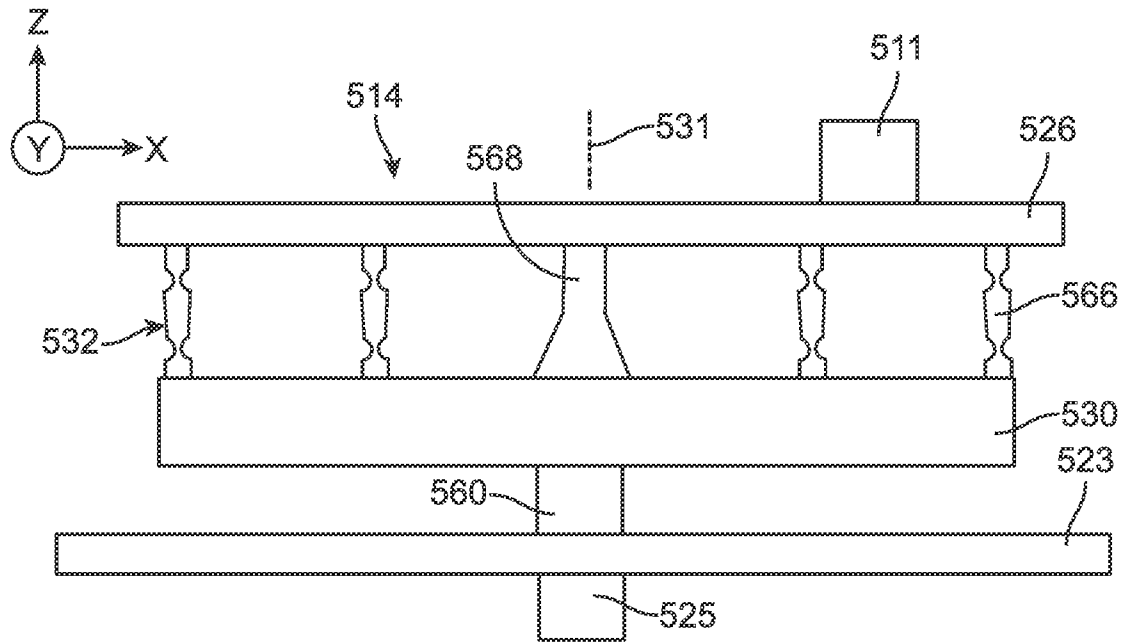


FIG. 5

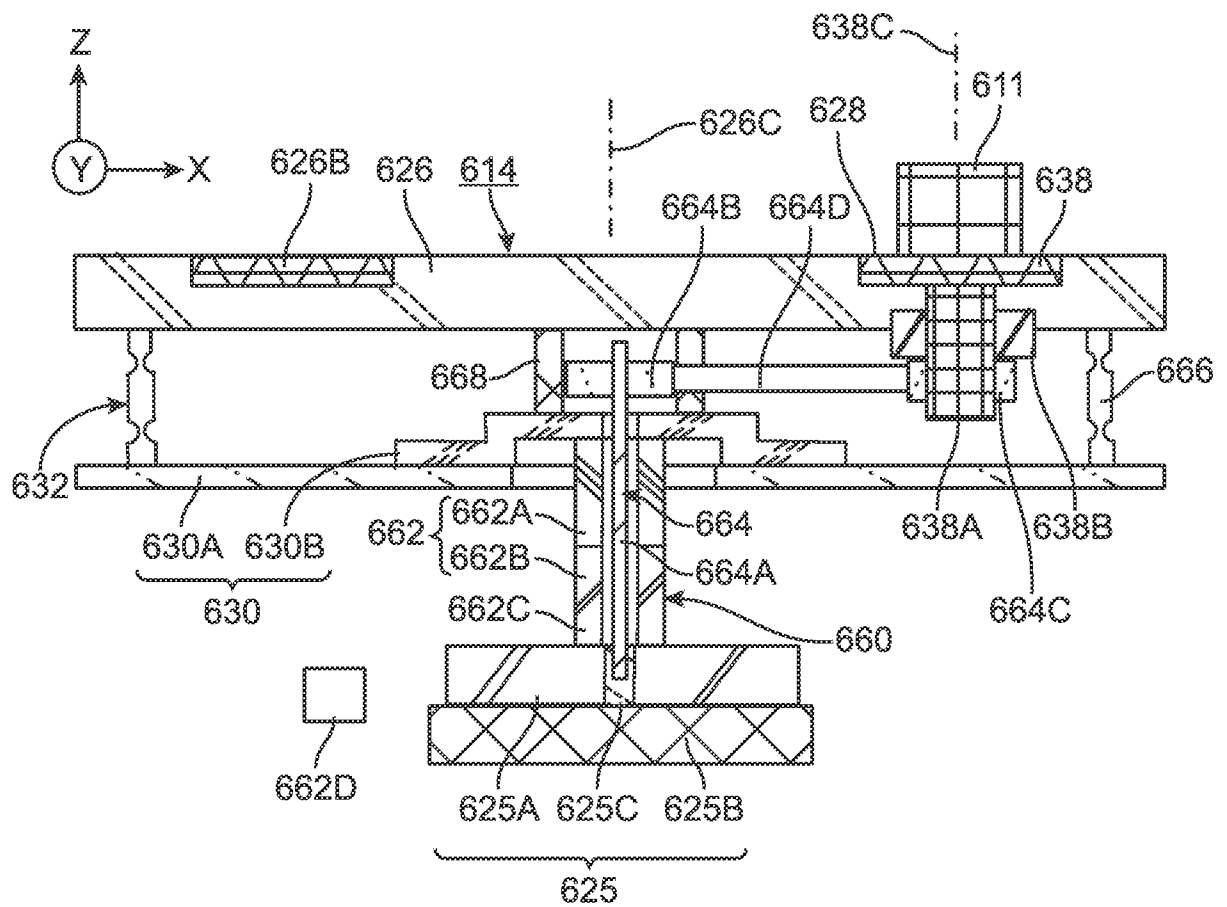


FIG. 6

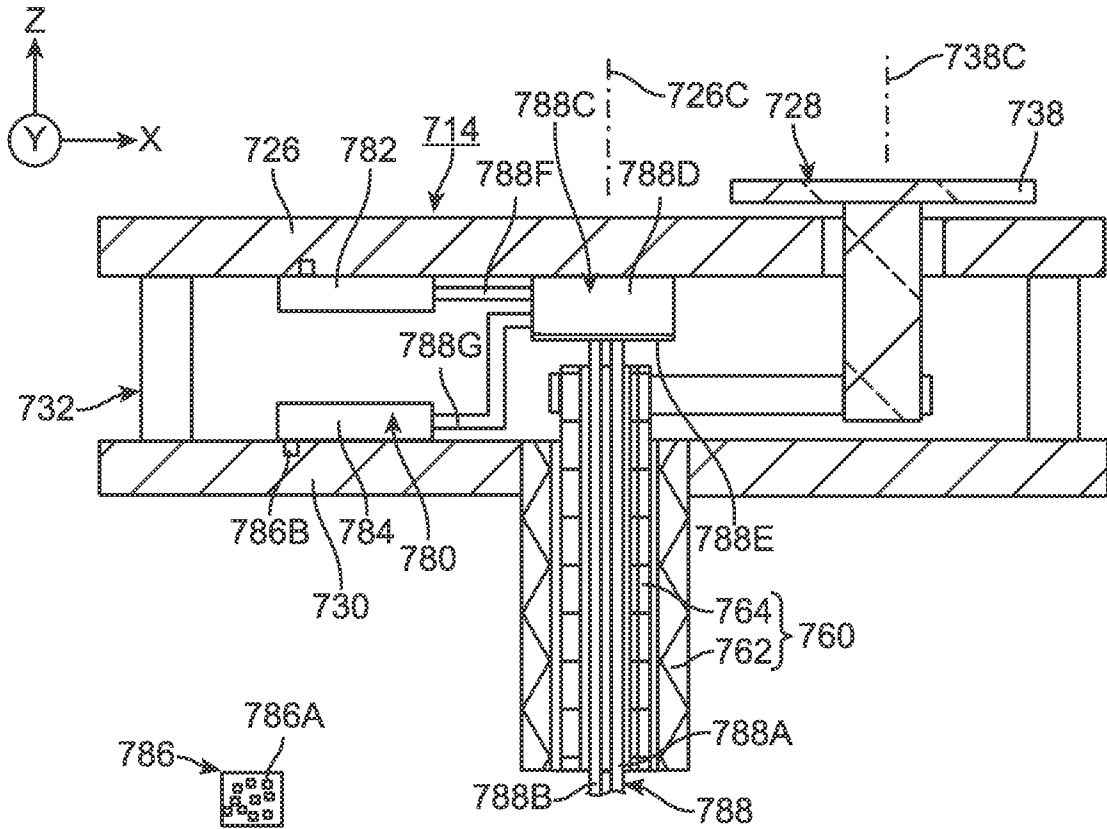


FIG. 7

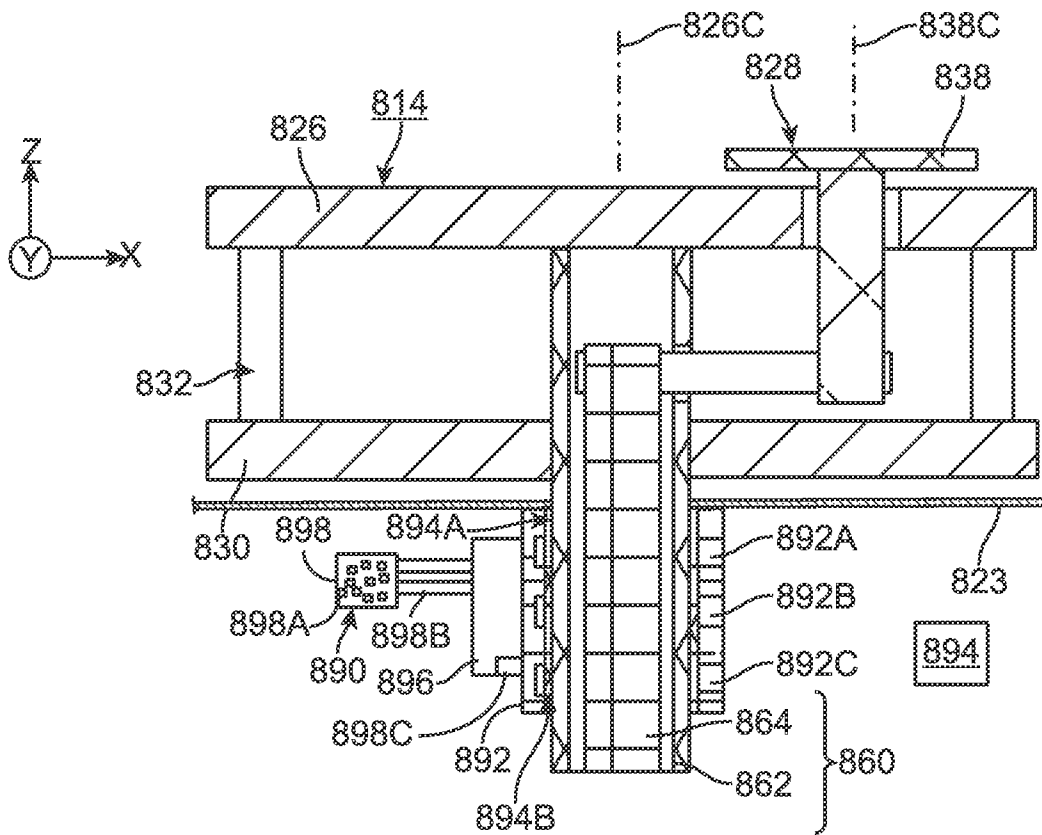


FIG. 8

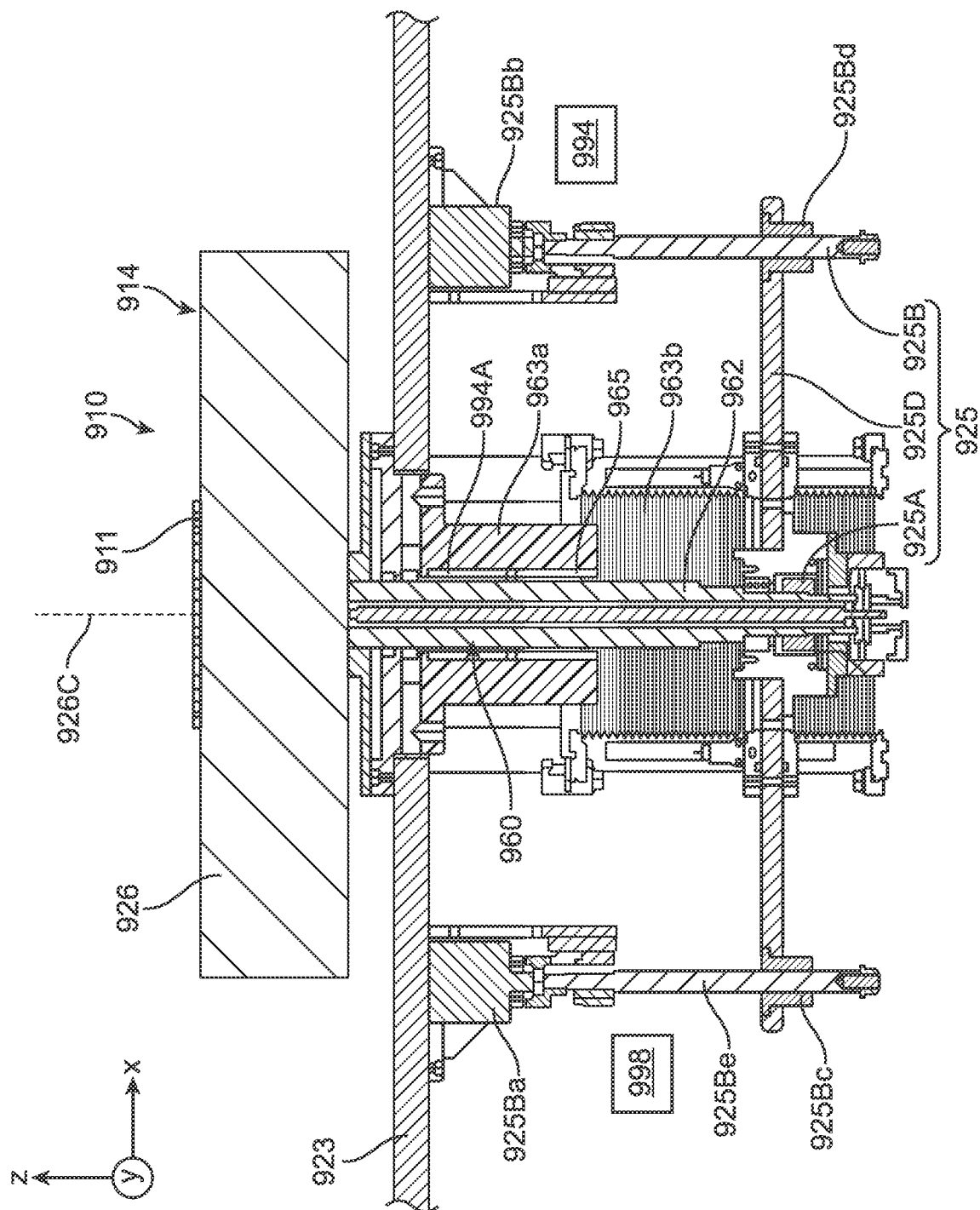


FIG. 9A

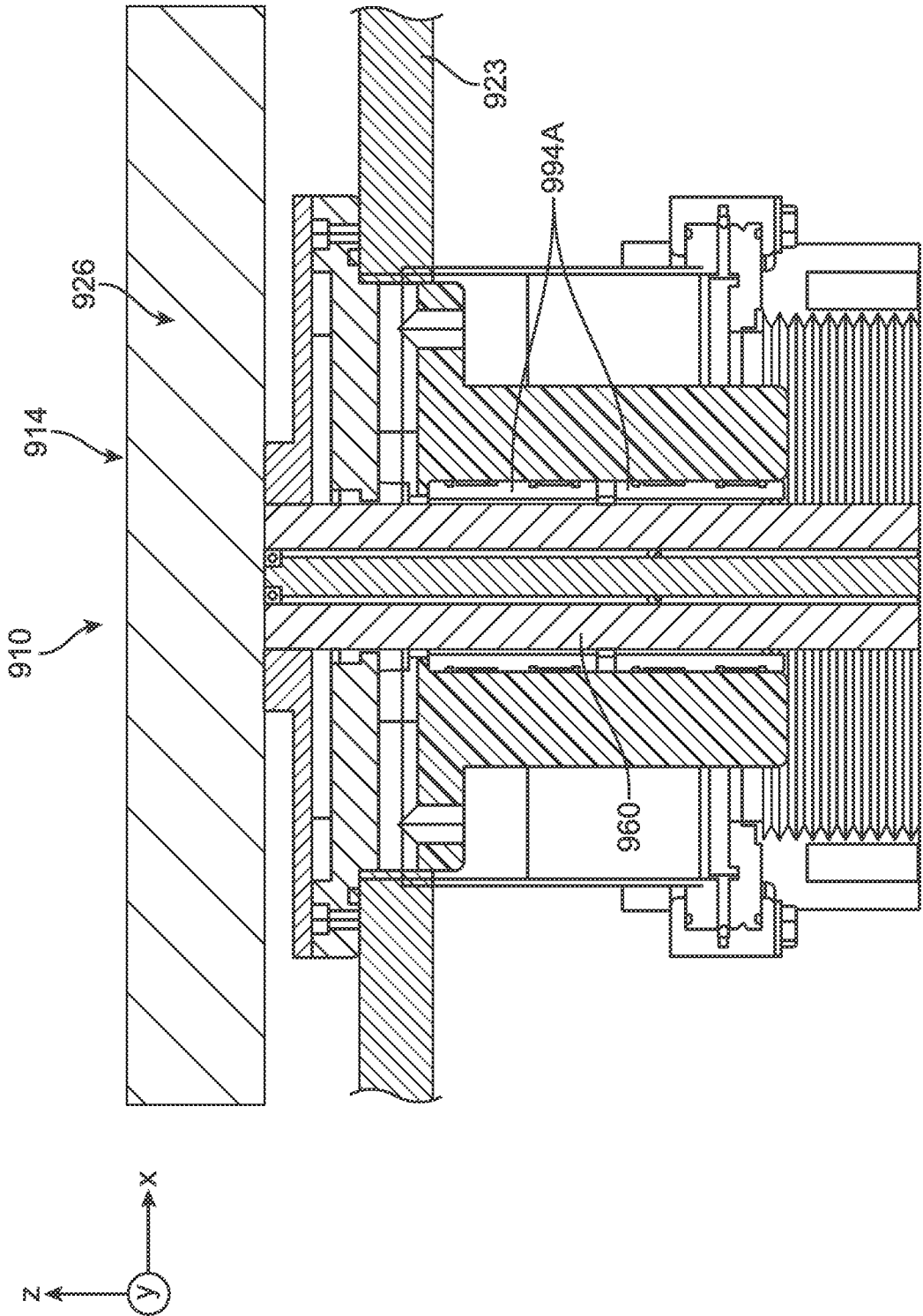


FIG. 9B

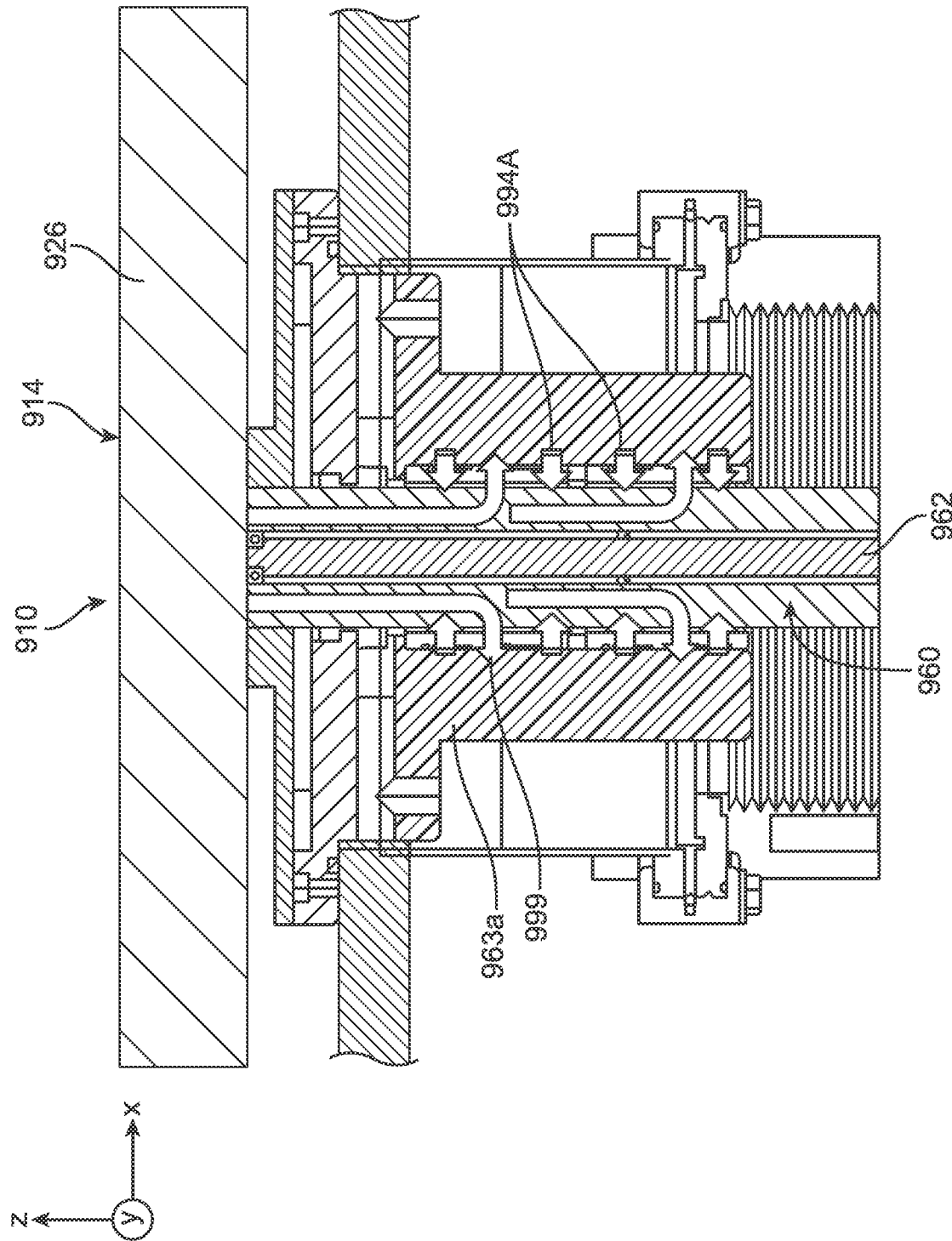


FIG. 9C

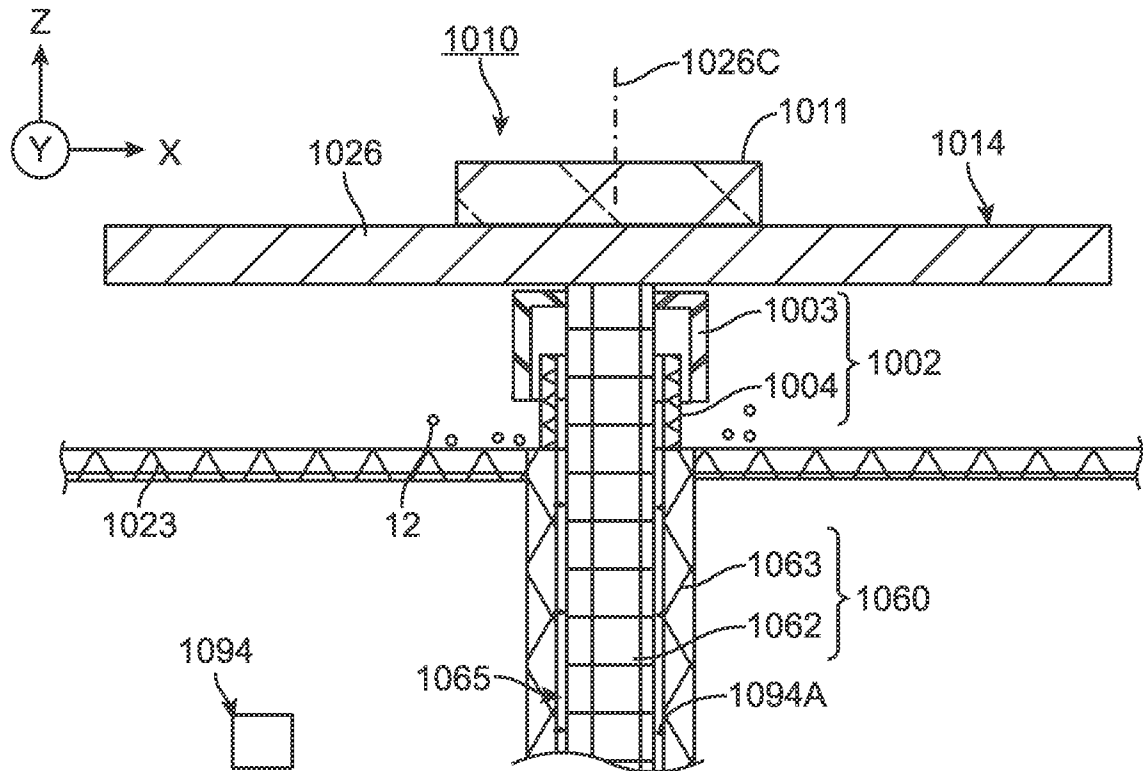


FIG. 10

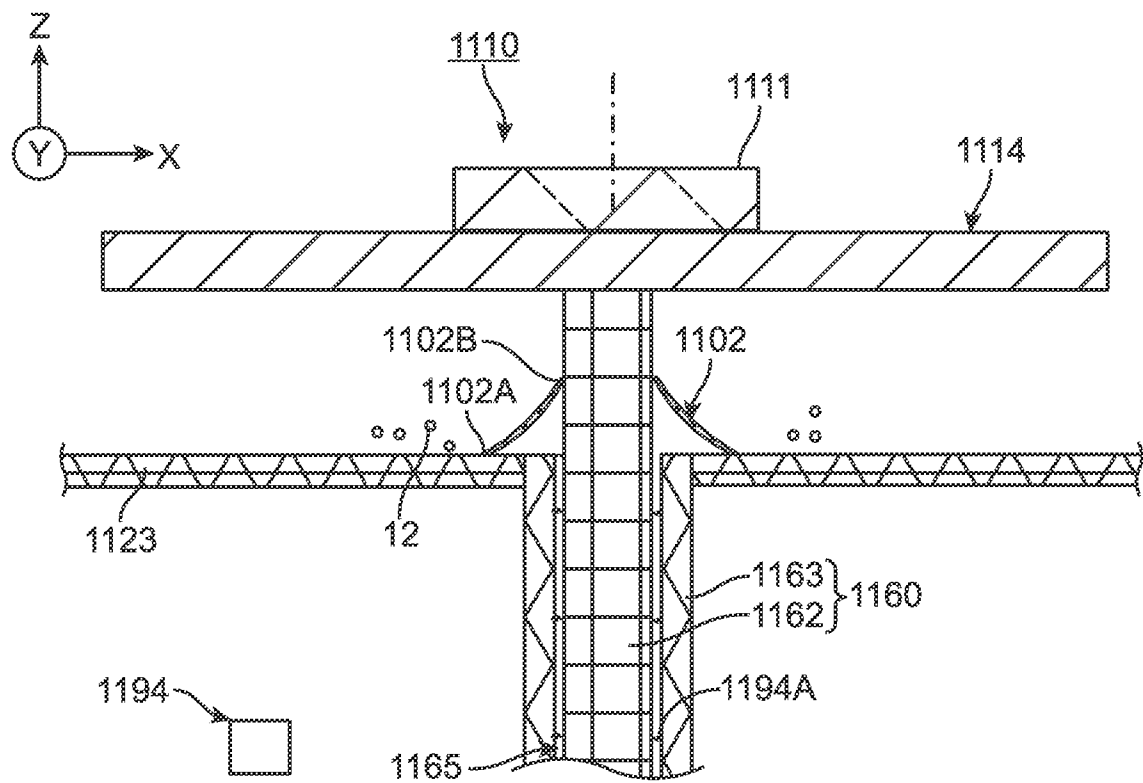


FIG. 11

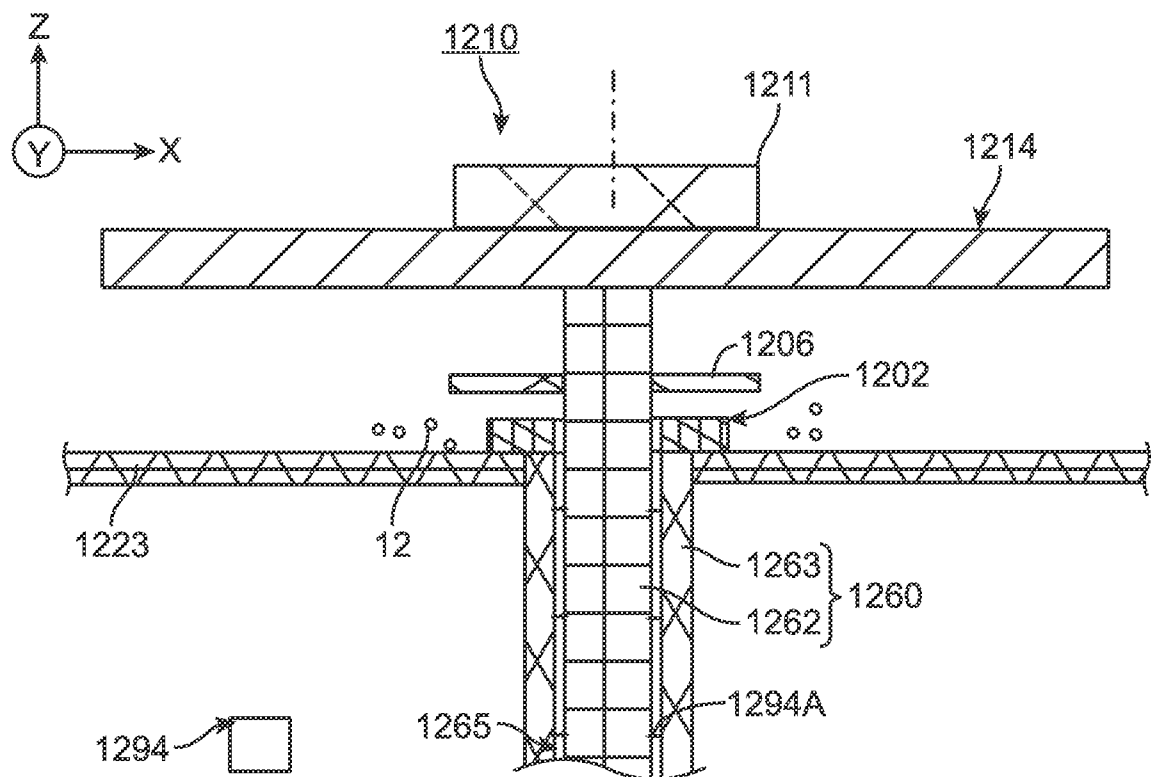


FIG. 12

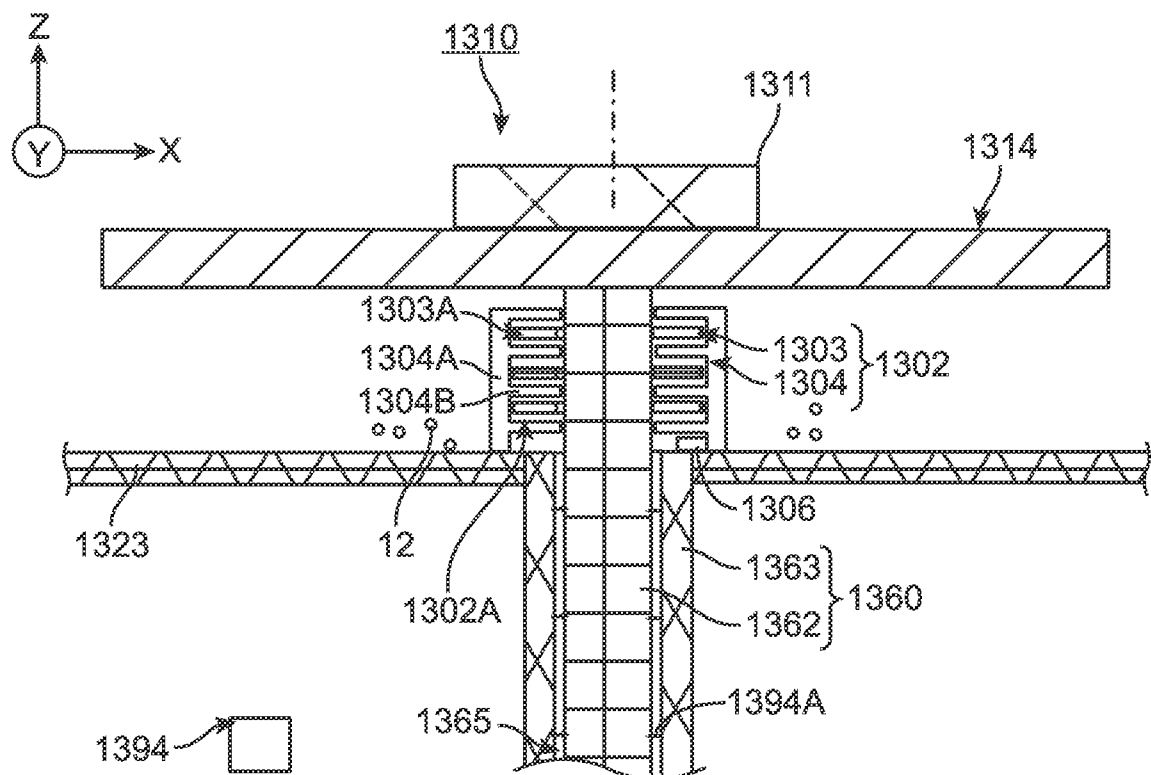


FIG. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2022/011247

A. CLASSIFICATION OF SUBJECT MATTER

INV. **B22F10/28** **B22F12/20** **B22F12/30** **B22F12/33** **B22F12/37**
B22F12/00 **B29C64/153** **B29C64/227** **B29C64/245** **B29C64/25**
B33Y10/00 **B33Y30/00**

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)

B22F C22C 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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 514 622 A1 (TRUMPF WERKZEUGMASCHINEN GMBH [DE]) 16 March 2005 (2005-03-16) paragraphs [0052] - [0055] figures 2-6 -----	1, 2, 4-13, 16-20, 59
X	EP 3 395 481 A1 (RENISHAW PLC [GB]) 31 October 2018 (2018-10-31) paragraphs [0106] - [0108], [0115] - [0118] figures 1-11 -----	1, 2, 4, 5, 12-15, 17-20, 59 3, 21-25
Y	WO 2019/133552 A1 (NIKON CORP [JP]) 4 July 2019 (2019-07-04) paragraphs [0059], [0075], [0076] figures 4, 6 -----	3, 21-25
	-/--	

☒ Further documents are listed in the continuation of Box C.

☒ 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

14 April 2022

Date of mailing of the international search report

21/06/2022

Name and mailing address of the ISA/
European Patent Office, P.B. 5818 Patentlaan 2
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Authorized officer

Knoflachner, Andreas

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2022/011247

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims;; it is covered by claims Nos.:

1-25, 59

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2022/011247

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 10 2017 216625 A1 (TRUMPF LASER & SYSTEMTECHNIK GMBH [DE]) 21 March 2019 (2019-03-21) paragraphs [0081], [0082] figure 13 -----	1, 2, 4, 5, 12, 13, 19, 20, 59
X	DE 10 2015 211538 A1 (TRUMPF LASER- UND SYSTEMTECHNIK GMBH [DE]) 29 December 2016 (2016-12-29) claims 1, 5 figures 1, 2 -----	1, 2, 4, 5, 12, 13, 19, 20, 59

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-25, 59

A processing machine for building a three-dimensional object from a material, the processing machine comprising a build platform that supports the material; an energy system that directs an energy beam at the material on the build platform to selectively melt the material, wherein the energy beam directed at the material generates heat that is transferred to the build platform; a first assembly that causes a movement of the build platform; and a second assembly at least part of which is arranged opposite to the energy system with respect to the build platform, the second assembly reducing the amount of heat therethrough transferred from the build platform.

2. claims: 26-40, 60

A processing machine for building a three-dimensional object from a material, the processing machine comprising a first support frame that supports the material; an energy system that directs an energy beam at the material to selectively melt the material; a mover assembly that causes relative movement between the first support frame and the energy system; and a coupler assembly that couples the mover assembly to the first support frame in a fashion that allows the first support frame to thermally expand.

3. claims: 41-54, 61

A processing machine for building a three-dimensional object from a material, the processing machine comprising a material bed assembly that supports the material; an energy system that directs an energy beam at the material on the material bed assembly to selectively melt the material; an environmental chamber that encloses the material bed assembly; an assembly mover assembly that selectively moves at least a portion of the material bed assembly, the assembly mover assembly being positioned outside of the environmental chamber, the assembly mover assembly including a drive shaft that extends through the environmental chamber and that is connected to the material bed assembly; and a fluid bearing that seals the shaft to the environmental chamber, the fluid bearing allowing the shaft to mover relative to the environmental chamber.

4. claims: 55-58, 62

A processing machine for building a three-dimensional object from a material, the processing machine comprising a

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

material bed assembly that supports the material; an energy system that directs an energy beam at the material on the material bed assembly to selectively melt the material; an environmental chamber that encloses the material bed assembly; an assembly mover assembly that selectively moves at least a portion of the material bed assembly, the assembly mover assembly being positioned outside of the environmental chamber, the assembly mover assembly including (i) a drive shaft that extends through the environmental chamber and that is connected to the material bed assembly, (ii) a connector housing that is coupled to the environmental chamber, the shaft being spaced apart from the connector housing by a bearing gap; and (iii) a bearing assembly that connects the drive shaft to the connector housing while allowing the drive shaft to move relative to the connector housing; and a material inhibitor that inhibits material in the environmental chamber from entering the bearing gap.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2022/011247

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