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(54) Title: 3-D-PRINTED COMPONENTS INCLUDING FASTENERS AND METHODS FOR PRODUCING SAME

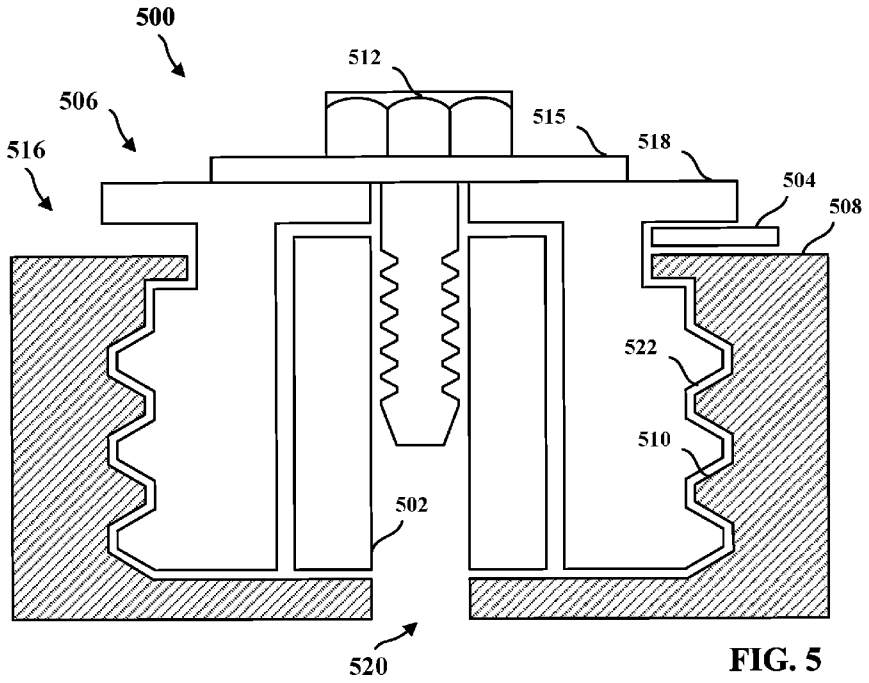


FIG. 5

(57) Abstract: One aspect is an apparatus including an additively manufactured first component and a captive nut contained within the first component for interconnecting the first component to a second component. Another aspect is an apparatus including a first additively manufactured component having a hole and a second additively manufactured component having a socket. The apparatus further includes a pin having a head engaging a surface of the first component and a shaft extending from the head through the hole in the first component and into the socket of the second component. Another aspect is an apparatus including first and second panels. The apparatus also includes a bolt having a head and a shaft extending from the head and a nut located at a distal end of the shaft. The first and seconds panels may be sandwiched between the bolt and nut to interconnect the first and second panels.

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[Continued on next page]

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3-D-PRINTED COMPONENTS INCLUDING FASTENERS AND METHODS FOR PRODUCING SAME

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Patent Application No. 15/627,103, entitled "3-D-PRINTED COMPONENTS INCLUDING FASTENERS AND METHODS FOR PRODUCING SAME" and filed on June 19, 2017, which is expressly incorporated by reference herein in its entirety.

BACKGROUND

Field

[0002] The present disclosure relates generally to apparatus and techniques in manufacturing, and more specifically to three-dimensional (3-D) printed components that include a fastener, the components for use in producing vehicles, boats, aircraft and other mechanical structures.

Background

[0003] 3-D printing, which may also be referred to as additive manufacturing, is a process used to create 3-D objects. The 3-D objects may be formed using layers of material based on digital model data of the object. A 3-D printer may form the layers of material using the digital model data to print one layer at a time. 3-D printed objects may be almost any shape or geometry.

[0004] A 3-D printer may disseminate a powder layer (e.g., powdered metal) on an operating surface. The powder layer may be approximately 100 microns thick. The 3-D printer may then bond particular areas of the powder layer into a layer of the object, e.g., by using a laser to bond the powder of the powder layer together. The steps may be repeated to sequentially form each layer. Accordingly, the 3-D printed object may be built layer by layer to form the 3-D object.

[0005] 3-D printed components may be used to produce sub-components for various devices or apparatus. The 3-D printed sub-components may need to be attached or connected to other sub-components, including other 3-D printed sub-components, extruded sub-components, or still other sub-components.

SUMMARY

[0006] Several aspects of 3-D printed components and related fasteners will be described more fully hereinafter with reference to three-dimensional printing techniques.

[0007] One aspect is an apparatus including an additively manufactured first component and a captive nut contained within the first component for interconnecting the first component to a second component.

[0008] Another aspect is an apparatus including a first additively manufactured component having a hole and a second additively manufactured component having a socket. The apparatus further includes a pin having a head engaging a surface of the first component and a shaft extending from the head through the hole in the first component and into the socket of the second component.

[0009] Another aspect is an apparatus including first and second panels. The apparatus also includes a bolt having a head and a shaft extending from the head and a nut located at a distal end of the shaft. The first and seconds panels may be sandwiched between the bolt and nut to interconnect the first and second panels.

[00010] It will be understood that other aspects of 3-D printed components and related fasteners will become readily apparent to those skilled in the art from the following detailed description, wherein it is shown and described only several embodiments by way of illustration. As will be realized by those skilled in the art, the 3-D printed components and related fasteners are capable of other and different embodiments, and its several details are capable of modification in various other respects, all without departing from the invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not as restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

[00011] Various aspects of 3-D printed components and related fasteners will now be presented in the detailed description by way of example, and not by way of limitation, in the accompanying drawings, wherein:

[00012] FIGS. 1A-D illustrate an example 3-D printer system during different stages of operation;

[00013] FIGS. 2A – 2B are diagrams illustrating a 1-way captive nut co-printed within a node;

[00014] FIG. 3 is a diagram illustrating a 2-way captive nut;

[00015] FIG. 4 is a diagram illustrating a 3-way captive nut and threaded shim;

[00016] FIG. 5 is a diagram illustrating a 3-way captive nut and threaded shim with a top piece attached to the connecting units via threads;

[00017] FIG. 6 is a diagram illustrating a nut co-printed into a node;

[00018] FIG. 7 is a diagram illustrating manufacturing tolerance issue;

[00019] FIG. 8 is a diagram illustrating a nut that may be installed after the node is printed rather than co-printed with the node;

[00020] FIG. 9 is a diagram illustrating a nut that may be installed after the node is printed rather than co-printed with the node;

[00021] FIG. 10 is a diagram illustrating a nut that may be installed after the node is printed rather than co-printed with the node;

[00022] FIG. 11 is a diagram illustrating a node-to-node connection using a hollow pin in place of a bolt to connect two nodes;

[00023] FIG. 12 is a flowchart illustrating an example method in accordance with the systems and methods described herein;

[00024] FIG. 13 is a flowchart illustrating an example method in accordance with the systems and methods described herein; and

[00025] FIG. 14 is a flowchart illustrating an example method in accordance with the systems and methods described herein.

DETAILED DESCRIPTION

[00026] The detailed description set forth below in connection with the appended drawings is intended to provide a description of various exemplary embodiments of 3-D printed components and related fasteners and is not intended to represent the only embodiments in which the invention may be practiced. The term "exemplary" used throughout this disclosure means "serving as an example, instance, or illustration," and should not necessarily be construed as preferred or advantageous over other embodiments presented in this disclosure. The detailed description includes specific details for the purpose of providing a thorough and complete disclosure that fully conveys the scope of the invention to those skilled in the art. However, the invention may be practiced without these specific details. In some instances, well-known structures and components may be shown in block diagram form, or omitted entirely, in order to avoid obscuring the various concepts presented throughout this disclosure.

[00027] The use of 3-D printing in the context of composite tooling provides significant flexibility for enabling manufacturers of mechanical structures and mechanized assemblies to manufacture parts with complex geometries. For example, 3-D printing techniques provide manufacturers with the flexibility to design and build parts having intricate internal lattice structures and/or profiles that are not possible to manufacture via traditional manufacturing processes.

[00028] FIGS. 1A-D illustrate respective side views of an exemplary 3-D printer system. In this example, the 3-D printer system is a powder-bed fusion (PBF) system 100. FIGS. 1A-D show PBF system 100 during different stages of operation. The particular embodiment illustrated in FIGS. 1A-D is one of many suitable examples of a PBF system employing principles of this disclosure. It should also be noted that elements of FIGS. 1A-D and the other figures in this disclosure are not necessarily drawn to scale, but may be drawn larger or smaller for the purpose of better illustration of concepts described herein. PBF system 100 can include a depositor 101 that can deposit each layer of metal powder, an energy beam source 103 that can generate an energy beam, a deflector 105 that can apply the energy beam to fuse the powder material, and a build plate 107 that can support one or more build pieces, such as a build piece 109. PBF system 100 can also include a build floor 111 positioned within a powder bed receptacle. The walls of the powder bed receptacle 112 generally define the boundaries of the powder bed receptacle, which is sandwiched between the walls 112 from the side and abuts a portion of the build floor 111 below. Build floor 111 can progressively lower build plate 107 so that depositor 101 can deposit a next layer. The entire mechanism may reside in a chamber 113 that can enclose the other components, thereby protecting the equipment, enabling atmospheric and temperature regulation and mitigating contamination risks. Depositor 101 can include a hopper 115 that contains a powder 117, such as a metal powder, and a leveler 119 that can level the top of each layer of deposited powder.

[00029] Referring specifically to FIG. 1A, this figure shows PBF system 100 after a slice of build piece 109 has been fused, but before the next layer of powder has been deposited. In fact, FIG. 1A illustrates a time at which PBF system 100 has already deposited and fused slices in multiple layers, e.g., 150 layers, to form the current state of build piece 109, e.g., formed of 150 slices. The multiple layers already deposited have created a powder bed 121, which includes powder that was deposited but not fused.

[00030] FIG. 1B shows PBF system 100 at a stage in which build floor 111 can lower by a powder layer thickness 123. The lowering of build floor 111 causes build piece 109 and powder bed 121 to drop by powder layer thickness 123, so that the top of the build piece and powder bed are lower than the top of powder bed receptacle wall 112 by an amount equal to the powder layer thickness. In this way, for example, a space with a consistent thickness equal to powder layer thickness 123 can be created over the tops of build piece 109 and powder bed 121.

[00031] FIG. 1C shows PBF system 100 at a stage in which depositor 101 is positioned to deposit powder 117 in a space created over the top surfaces of build piece 109 and powder bed 121 and bounded by powder bed receptacle walls 112. In this example, depositor 101 progressively moves over the defined space while releasing powder 117 from hopper 115. Leveler 119 can level the released powder to form a powder layer 125 that has a thickness substantially equal to the powder layer thickness 123 (*see* FIG. 1B). Thus, the powder in a PBF system can be supported by a powder material support structure, which can include, for example, a build plate 107, a build floor 111, a build piece 109, walls 112, and the like. It should be noted that the illustrated thickness of powder layer 125 (i.e., powder layer thickness 123 (FIG. 1B)) is greater than an actual thickness used for the example involving 150 previously-deposited layers discussed above with reference to FIG. 1A.

[00032] FIG. 1D shows PBF system 100 at a stage in which, following the deposition of powder layer 125 (FIG. 1C), energy beam source 103 generates an energy beam 127 and deflector 105 applies the energy beam to fuse the next slice in build piece 109. In various exemplary embodiments, energy beam source 103 can be an electron beam source, in which case energy beam 127 constitutes an electron beam. Deflector 105 can include deflection plates that can generate an electric field or a magnetic field that selectively deflects the electron beam to cause the electron beam to scan across areas designated to be fused. In various embodiments, energy beam source 103 can be a laser, in which case energy beam 127 is a laser beam. Deflector 105 can include an optical system that uses reflection and/or refraction to manipulate the laser beam to scan selected areas to be fused.

[00033] In various embodiments, the deflector 105 can include one or more gimbals and actuators that can rotate and/or translate the energy beam source to position the energy beam. In various embodiments, energy beam source 103 and/or deflector 105 can modulate the energy beam, e.g., turn the energy beam on and off as the deflector scans

so that the energy beam is applied only in the appropriate areas of the powder layer. For example, in various embodiments, the energy beam can be modulated by a digital signal processor (DSP).

[00034] FIGS. 2A – 2B are diagrams 200 illustrating a 1-way captive nut 202 co-printed (co-additively manufactured) within a node 204 forming a connecting unit 206. In some examples, the 1-way captive nut 202 may be used for nonstructural connections. In other words, in some examples, the 1-way captive nut 202 may be used for connections that are not load carrying.

[00035] When the 1-way captive nut 202 is used to form a connection, a bolt (not shown) may be inserted through a hole 208 in the connecting unit 206 and into the nut 202. The nut 202 may hold the bolt. For example, in one aspect, the nut 202 may be threaded, e.g., the threads may be co-printed with the nut 202. In another aspect, the nut 202 may initially be unthreaded, e.g., the nut 202 may be threaded after the nut 202 is printed. In yet another aspect, the nut 202 may use some other means of securing the bolt within the nut 202, e.g., a friction fit or other suitable mechanism may be used. Forming threads in the nut 202 after printing the nut 202 may in some embodiments allow for more precise threads to be formed when compared to 3-D printing (additive manufacturing) of threads using certain 3-D printers.

[00036] In an example, the connection unit 206 may allow an apparatus to form a connection. The apparatus (e.g., connection unit 206) may include an additively manufactured first component, such as the node 204. A captive nut 202 may be contained within the first component (e.g., node 204) for interconnecting the first component (e.g., node 204) to a second component (not shown). In an aspect, the captive nut 202 may be co-printed with the first component (e.g., node 204). In another aspect, the threads may also be additively manufactured. For example, the threads may also be printed on the nut 202, as the nut 202, and the first component (e.g., the node 204) are co-printed. An anti-rotation aspect 210 may be included. The anti-rotation aspect 210 may be formed adjacent to a flat aspect of the nut 202 to keep the nut 202 from rotating. In an aspect, the 1-way captive nut 202 may float in the x-direction.

[00037] FIG. 3 is a diagram 300 illustrating a 2-way captive nut design 306. A connection unit using a 2-way captive nut design 306 may include a nut 302 allowing for float in both the x-direction and the y-direction. The 2-way captive nut may also provide for anti-rotation 308. A connection unit using a 2-way captive nut design 306 may include a nut 302 that may be threaded or unthreaded. For example, in one aspect,

the nut 302 may be threaded, e.g., the threads may be co-printed with the nut 302. In another aspect, the nut 302 may initially be unthreaded, e.g., the nut 302 may be threaded after the nut 302 is printed. In yet another aspect, the nut 302 may use some other means of securing the bolt within the nut 302, e.g., a friction fit or other suitable mechanism may be used.

[00038] For example, an apparatus (2-way captive nut design 306) may include an additively manufactured first component 304 and a captive nut 302 contained within the first component 304 for interconnecting the first component 304 to a second component. The captive nut 302 may be co-printed with the first component 304. In an aspect, the captive nut 302 comprises threads. In another aspect, the threads are additively manufactured. In an aspect, the captive nut 302 may float within the first component 304. The captive nut 302 may be a 2-way captive nut. In an aspect, the captive nut 302 is prevented from rotating by the first component. The 2-way captive nut 302 may be used for nonstructural connections between nodes (e.g., 304) and/or other units.

[00039] FIG. 4 is a diagram 400 illustrating a 3-way captive nut 402 and threaded shim 404. The threaded shim 404 may be installed into an additively manufactured first component 406, such as a node. In an aspect, the 3-way captive nut 402 may be within a holder 408 contained within the component 406 by threaded shim 404. The 3-way captive nut 402 and threaded shim 404 may be used to connect nodes and/or other units. The structure of a connection using the 3-way captive nut 402, threaded shim 404, and component 406 may be similar to the structure using the 1-way captive nut 202 of FIG. 2 and/or the 2-way captive nut 302 of FIG. 3.

[00040] In an example, a difference between a connection using the 1-way captive nut 202 of FIG. 2 and a connection using the 3-way captive nut 302 of FIG. 3 may be that the floating nut 302 may be contained within, e.g., three separate pieces (the threaded shim 304, the component 306, the holder 308) that are joined together instead of one continuous socket as in the apparatus of FIG. 2). In an example, a difference between a connection using the 2-way captive nut 302 of FIG. 3 and a connection using the 3-way captive nut 402 of FIG. 4 may be that the floating nut 402 may be contained within, e.g., three separate pieces (the threaded shim 404, the component 406, the holder 408) that are joined together instead of a socket capturing the nut in 2 directions as in the apparatus of FIG. 3). In an example, the nut 402 may be co-printed into the

component 406, e.g., a node. The nut may be threaded or unthreaded. In some aspects, the 3-way captive nut 402 may be used for nonstructural connections.

[00041] FIG. 5 is a diagram 500 illustrating a 3-way captive nut 502 and threaded shim 504 with a top piece 506 attached to the connecting unit 508 via threaded portion 510 as in FIG. 4, however, in FIG. 5, the top piece 506 is attached to the connecting unit 508 via the threaded portion 510 rather than a flat connection as in FIG. 4. A bolt 512 may be used to connect other components 514, e.g., nodes. The bolt 512 may be screwed into the nut 502 after the other parts (e.g., the 3-way captive nut 502, the threaded shim 504, and the top piece 506) are printed to complete an assembly 516. The shim 504 may be wedged between an "upper T-part" 518 of the top piece 506 and the connecting unit 508 and other node(s) or other components involved. The nut may be threaded or unthreaded.

[00042] In an aspect, an apparatus (e.g., assembly 516) may include an additively manufactured first component (e.g., connecting unit 508) and a captive nut 502 contained within the first component (e.g., connecting unit 508) for interconnecting the first component to a second component. The apparatus (e.g., assembly 516) may further include a shim 504 which together with the first component (e.g., connecting unit 508) forms a cavity 520 and allows the nut 502 to move along an axial axis of the nut 502. The apparatus (e.g., assembly 516) may further include an insert (top piece 506) forming the cavity 520. For example, the first component (e.g., connecting unit 508) may be engaged with the insert (top piece 506), and the nut 502 may be contained within the cavity 520.

[00043] In an aspect, the first component (e.g., connecting unit 508) may include an additively manufactured threaded portion 510 and the insert (top piece 506) may include a threaded insert 522 engaged with the threaded portion 510 of the first component (e.g., connecting unit 508). The shim 504 may be between a portion of the first component (e.g., connecting unit 508) and the insert (top piece 506).

[00044] FIG. 6 is a diagram 600 illustrating a nut 602 co-printed into a node 604. The nut 602 is co-printed into the node 604 similar to the example illustrated in FIG. 4; however, the nut 602 in the example of FIG. 6 is surrounded by spherical captive housing 606. The spherical captive housing 606 may have a cutout 608 that encases the upper, flat part of the nut 602 with enough space to allow for radial float. A shim 610 may be printed with right-hand threads and may be installed on top of the node 604. The nut 602 may be threaded or unthreaded. In an aspect, an apparatus 612 may include an

additively manufactured first component (e.g., node 604) and a captive nut 602. The captive nut 602 may be contained within the first component (e.g., node 604) for interconnecting the first component (e.g., node 604) to a second component (not shown). The apparatus 612 may include an additively manufactured semi-spherical housing 606 that may be co-printed with the first component (e.g., node 604) and the nut 602. In an aspect, the nut may be contained within the first component (e.g., node 604) by the semi-spherical housing 606.

[00045] FIG. 7 is a diagram illustrating manufacturing tolerance issue. The issues may be observed in conventional manufacturing. The manufacturing tolerance issue may be resolved using 3-D printing. For example, the apparatus 612 of FIG. 6 may be used to address some manufacturing tolerance issues.

[00046] In an aspect, two components (e.g., component 702 and apparatus 612) to be connected together may be angled relative to each other as illustrated in FIG. 7. More particularly, bolt holes 704 may be angled relative to each other. The additively manufactured semi-spherical housing 606 illustrated in FIG. 6 may provide for adjustments to the angle of one of the bolt holes 704, e.g., the bolt hole in the apparatus 612. In an aspect, the nut may be contained within the first component (e.g., node 604) by the semi-spherical housing 606. For example, the additively manufactured semi-spherical housing 606 illustrated in FIG. 6 may allow the angle of one of the bolt holes 704, e.g., the bolt hole in the apparatus 612 to be adjusted such that the bolt holes 704 are parallel or nearly parallel and line up with each other such that a bolt may be installed through the bolt holes 704.

[00047] FIG. 8 is a diagram 800 illustrating a nut 802 that may be installed after the node 804 is 3-D printed (additively manufactured) rather than co-printed with the node 804. In an aspect, for structural connections, the nut 802 may be installed after the node 804 is printed (additively manufactured) rather than co-printed with the node. Instead, a retainer plate 806 may be co-printed within the node 804 in the closed position. At a time of assembly, a captive tab 812 may be depressed, causing the plate to be temporarily stored in a slot 808 within the node 804 so that the nut 802 may be inserted into a cavity 810 in the node 804. The tab 812 may then be released, which may cause the retainer plate 806 to slide out so as to form a barrier and keep the nut 802 from sliding out of the cavity 810.

[00048] In an aspect, an apparatus 814 may include an additively manufactured first component (e.g., node 804) and a captive nut 802. The captive nut 802 may be

contained within the first component for interconnecting the first component (e.g., node 804) to a second component. In an aspect, the apparatus may further include an additively manufactured retainer plate 806 which, together with the first component (e.g., node 804), may form a cavity 810. The nut 802 may be contained within the cavity 810. The retainer plate 806 may be configured to be slid within a slot 808 within the first component (e.g., node 804) to install the captive nut 802 and the retainer plate 806 may be configured to slide out of the slot 808 within the first component (e.g., node 804) to retain the captive nut 802. The tab 812 may slide along a groove 816 to move the retainer plate 806 into and out of the slot 808.

[00049] FIG. 9 is a diagram 900 illustrating a nut 902 that may be installed after the node 904 is printed rather than co-printed with the node. As in the example of FIG. 8 (captive nut 702), the nut 902 in FIG. 9 may be held in place through the use of a retainer plate 906 instead of being co-printed. Unlike the example of FIG. 7, however, the example of FIG. 9 may use either a captive lug or a captive stud 908 to facilitate the closing and releasing of the retainer plate 906. A threaded shim 910 (e.g., a right-handed threaded shim) may be installed over the nut 902 so that a bolt (not shown) may slip through the shim 910 before entering the node 904. The retainer structure 912 may be co-printed and may include a retainer slot 914.

[00050] In an aspect, an apparatus (retainer structure 912) may include an additively manufactured first component (e.g., a node 904) and a captive nut 902. The captive nut 902 may be contained within the first component (e.g., a node 904) for interconnecting the first component (e.g., a node 904) to a second component (not shown). The apparatus (retainer structure 912) may further include an additively manufactured retainer plate 906 which, together with the first component (e.g., a node 904), forms a cavity 916. The nut 902 may be contained within the cavity 916. A captive lug or a captive stud 908 may facilitate the closing and releasing of the retainer plate 906.

[00051] FIG. 10 is a diagram 1000 illustrating a nut 1002 that may be installed after the node 1004 is 3-D printed (additively manufactured) rather than co-printed with the node 1004. Diagram 1000 illustrates an example of a rotating retainer plate 1006 that may be used with the structures described herein as well as other structures. The example of FIG. 10 may be used in place the tab system described with respect to FIGS. 8 and 9 that uses plates that slide in and out of a slot.

[00052] In the example of FIG. 10, a retainer plate 1006 may be co-printed in the node with a hexagonal socket 1008 through which a slightly smaller hexagonal nut 1002 or stud may be inserted. Once the nut 1002/stud is inserted in the socket 1008, a hexagonal key 1010 may be used to rotate the retainer plate 1006 30 degrees to hold the nut 1002/stud in place.

[00053] In an example, an apparatus may include an additively manufactured first component (e.g., node 1004) and a captive nut 1002. The nut 1002 may be contained within the first component (e.g., node 1004) for interconnecting the first component (e.g., node 1004) to a second component (not shown). The retainer plate 1006 may be rotatable between a first position to open the cavity to place the nut 1002 therein and a second position to lock the nut 1002 in the cavity.

[00054] FIG. 11 is a diagram 1100 illustrating a node-to-node connection using a hollow pin 1102 in place of a bolt to connect two nodes 1104, 1106. As illustrated in FIG. 11, the hollow pin 1102 may be used in place of a bolt to connect two nodes 1104, 1106. The pin 1102 may be inserted through an open-faced node (node 1106) and into a socket 1108 within another node (node 1104). Adhesive, thermoset, thermoplastic, or brazing may be used to secure the connection, e.g., at the socket 1108. The hollow pin 1102 may hold the nodes together similarly to a bolt. Additionally, the hollow pin may include adhesive channels 1110 to allow adhesive to be input through the hollow pin 1102 to adhere the hollow pin to one or more of the nodes 1104, 1106.

[00055] In an aspect, an apparatus 1112 may include a first additively manufactured component (e.g., node 1106) having a hole 1114. The apparatus 1112 may include a second additively manufactured component (e.g., node 1104) having a socket 1108. The apparatus 1112 may also include a pin 1102 having a head 1116 engaging a surface 1118 of the first component (e.g., node 1106) and a shaft 1120 extending from the head 1116 through the hole 1114 in the first component (e.g., node 1106) and into the socket 1108 of the second component (e.g., node 1104).

[00056] In an aspect, the pin 1102 include an adhesive injection channel 1110 extending from the head 1116 through the shaft 1120. The channel 1110 may be in communication with the hole 1114, the first component (e.g., node 1106) and a slot 1122 in the second component (e.g., node 1104).

[00057] In an aspect, the apparatus 1112 may further include an adhesive extending through the channel 1110 of the pin 1102 and into the hole 1114 of the first component (e.g., node 1106) and slot 1122 of the second component (e.g., node 1104).

[00058] In an aspect, the apparatus 1112 may further include a seal 1124 between the first component (e.g., node 1106) and second components (e.g., node 1104) to seal the adhesive in the hole 1114 of the first component (e.g., node 1106) and the slot 1122 of the second component (e.g., node 1104).

[00059] FIG. 12 is a flowchart 1200 illustrating an example method in accordance with the systems and methods described herein. At a block 1202, additively manufacture a first component. For example, additively manufacture a first component (e.g., 204, 304, 406, 508, 604, 804, 904, 1004) using an exemplary 3-D printer.

[00060] At a block 1204, additively manufacture a captive nut contained within the first component for interconnecting the first component to a second component. For example, additively manufacture a captive nut (e.g., nut 202, 302, 402, 502, 602, 802, 902, 1002) contained within first component (e.g., 204, 304, 406, 508, 604, 804, 904, 1004) for interconnecting the first component (e.g., 204, 304, 406, 508, 604, 804, 904, 1004) to a second component. In an aspect, additively manufacturing the captive nut (e.g., nut 202, 302, 402, 502, 602, 802, 902, 1002) may include co-printing the captive nut (e.g., nut 202, 302, 402, 502, 602, 802, 902, 1002) with the first component (e.g., 304, 406, 508, 604, 804, 904, 1004). In an aspect, additively manufacturing the captive nut (e.g., nut 202, 302, 402, 502, 602, 802, 902, 1002) may include forming threads. Forming threads may include additively manufacturing the threads. In an aspect, the captive nut (e.g., nut 202, 302, 402, 602) may be additively manufactured to float within the first component (e.g., 204). In an aspect, the first component (e.g., 204) may be additively manufactured to prevent the captive nut from rotating.

[00061] At block 1206, additively manufacture a semi-spherical housing co-printed with the first component and the nut, wherein the nut is contained within the first component by the semi-spherical housing. For example, additively manufacture a semi-spherical housing (606) co-printed with the first component (e.g., node 604) and the nut (602). The nut (602) may be contained within the first component (e.g., node 604) by the semi-spherical housing (606).

[00062] At block 1208, add a shim, which together with the first component, forms a cavity and allows the nut to move along an axial axis of the nut. For example, add a shim (404), which together with the first component (406), forms a cavity and allows the nut (402) to move along an axial axis of the nut (402). In an aspect, adding the shim (404) may include threading the shim to the first component (406).

[00063] At block 1210, form an insert having a cavity, wherein the first component is engaged with the insert, and the nut is contained within the cavity. For example, form an insert (506) having a cavity (520), wherein the first component (508) is engaged with the insert (506), and the nut (502) is contained within the cavity (520). In an aspect, additively manufacturing the first component (508) includes forming an additively manufactured threaded portion (510) and further comprising forming the insert (506) to include a threaded (522) insert (506) engaged with the threaded portion (510) of the first component (508).

[00064] At block 1212, add a shim between a portion of the first component and the insert. For example, add a shim (504) between a portion of the first component (508) and the insert (506).

[00065] FIG. 13 is a flowchart 1300 illustrating an example method in accordance with the systems and methods described herein. At block 1302, additively manufacture a retainer plate, which together with the first component forms a cavity, wherein the nut is contained within the cavity. For example, additively manufacture a retainer plate (806) which together with the first component (e.g., node 804) forms a cavity (810). The nut (802) may be contained within the cavity (810).

[00066] At block 1304, form the retainer plate to be slid within a slot within the first component to install the captive nut and form the retainer plate to slide out of the slot within the first component to retain the captive nut. For example, form the retainer plate (806) to be slid within a slot (808) within the first component (e.g., node 804) to install the captive nut (802) and form the retainer plate (806) to slide out of the slot (808) within the first component (e.g., node 804) to retain the captive nut (802). In an aspect, the retainer plate (806) may be additively manufactured to be rotatable between a first position to open the cavity (810) to place the nut (802) therein and a second position to lock the nut (802) in the cavity (810).

[00067] In block 1306, form at least one of a captive lug or a captive stud configured to facilitate the closing and releasing of the retainer plate. For example, form at least one of a captive lug or a captive stud (908) configured to facilitate the closing and releasing of the retainer plate (906). In an aspect, additively manufacturing the first component includes additively manufacturing a node (204, 604, 804, 904, 1004).

[00068] FIG. 14 is a flowchart 1400 illustrating an example method in accordance with the systems and methods described herein. In a block 1402, additively manufacture a

first component having a hole. For example, additively manufacture a first component (e.g., node 1106) having a hole (1114).

[00069] In a block 1404, additively manufacture a second component having a socket. For example, additively manufacture a second component (e.g., node 1104) having a socket (1108).

[00070] In block 1406, form a pin having a head engaging a surface of the first component and a shaft extending from the head through the hole in the first component and into the socket of the second component. For example, form a pin (1102) having a head (1116) engaging a surface (1118) of the first component (e.g., node 1106) and a shaft extending from the head (1116) through the hole (1114) in the first component (e.g., node 1106) and into the socket (1108) of the second component (e.g., node 1104).

[00071] In block 1408, form the pin to include an adhesive injection channel extending from the head through the shaft. The channel may be in communication with the hole the first component and a slot in the second component. For example, form the pin (1102) to include an adhesive injection channel (1110) extending from the head (1116) through the shaft. The channel (1110) may be in communication with the hole (1114) the first component (e.g., node 1106) and a slot (1122) in the second component (e.g., node 1104).

[00072] In block 1410, add an adhesive extending through the channel of the pin and into the hole of the first component and slot of the second component. For example, add an adhesive extending through the channel (1110) of the pin (1102) and into the hole (1114) of the first component (e.g., node 1106) and slot (1122) of the second component (e.g., node 1104).

[00073] In block 1412, form a seal between the first and second components to seal the adhesive in the hole of the first component and the slot of the second component. For example, form a seal (1124) between the first and second components (e.g., nodes 1106, 1104) to seal (1124) the adhesive in the hole (1114) of the first component (e.g., node 1106) and the slot (1122) of the second component (e.g., node 1104).

[00074] The previous description is provided to enable any person skilled in the art to practice the various aspects described herein. Various modifications to these exemplary embodiments presented throughout this disclosure will be readily apparent to those skilled in the art, and the concepts disclosed herein may be applied to 3-D printed components and fasteners. Thus, the claims are not intended to be limited to the exemplary embodiments presented throughout the disclosure, but are to be accorded

the full scope consistent with the language claims. All structural and functional equivalents to the elements of the exemplary embodiments described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under the provisions of 35 U.S.C. §112(f), or analogous law in applicable jurisdictions, unless the element is expressly recited using the phrase "means for" or, in the case of a method claim, the element is recited using the phrase "step for."

WHAT IS CLAIMED IS:

1. An apparatus, comprising:

an additively manufactured first component; and

a captive nut contained within the first component for interconnecting the first component to a second component.

2. The apparatus of claim 1, wherein the captive nut is co-printed with the first component.

3. The apparatus of claim 1, wherein the captive nut comprises threads.

4. The apparatus of claim 3, wherein the threads are additively manufactured.

5. The apparatus of claim 1, wherein the captive nut floats within the first component.

6. The apparatus of claim 1, wherein the captive nut is prevented from rotating by the first component.

7. The apparatus of claim 1, further comprising an additively manufactured semi-spherical housing co-printed with the first component and the nut, wherein the nut is contained within the first component by the additively manufactured semi-spherical housing.

8. The apparatus of claim 1, further comprising a shim which together with the first component forms a cavity and allows the nut to move along an axial axis of the nut.

9. The apparatus of claim 8, wherein the shim is threaded to the first component.

10. The apparatus of claim 1, further comprising an insert having a cavity, wherein the first component is engaged with the insert and the nut is contained within the cavity.

11. The apparatus of claim 10, wherein the first component comprises an additively manufactured threaded portion and the insert comprises a threaded insert engaged with the threaded portion of the first component.

12. The apparatus of claim 10, further comprising a shim between a portion of the first component and the insert.

13. The apparatus of claim 1, further comprising an additively manufactured retainer plate which together with the first component forms a cavity, wherein the nut is contained within the cavity.

14. The apparatus of claim 13, wherein the retainer plate is configured to be slid within a slot within the first component to install the captive nut and the retainer plate is configured to slide out of the slot within the first component to retain the captive nut.

15. The apparatus of claim 13, wherein the retainer plate is rotatable between a first position to open the cavity to place the nut therein and a second position to lock the nut in the cavity.

16. The apparatus of claim 13, further comprising at least one of a captive lug or a captive stud configured to facilitate the closing and releasing of the retainer plate.

17. The apparatus of claim 1, wherein at least one of the first component and the second component comprises a node.

18. An apparatus, comprising:

a first additively manufactured component having a hole;

a second additively manufactured component having a socket; and

a pin having a head engaging a surface of the first component and a shaft extending from the head through the hole in the first component and into the socket of the second additively manufactured component.

19. The apparatus of claim 18, wherein the pin comprises an adhesive injection channel extending from the head through the shaft, the adhesive injection channel in

communication with the hole the first component and a slot in the second additively manufactured component.

20. The apparatus of claim 19, further comprising an adhesive extending through the adhesive injection channel of the pin and into the hole of the first component and the slot of the second additively manufactured component.

21. The apparatus of claim 20, further comprising a seal between the first and second components to seal the adhesive in the hole of the first component and the slot of the second additively manufactured component.

22. An apparatus, comprising:

first and second panels;

a bolt having a head and a shaft extending from the head; and

a nut located at a distal end of the shaft;

wherein the first and seconds panels are sandwiched between the bolt and nut to interconnect the first and second panels.

23. The apparatus of claim 22, further comprising a component surrounding the shaft of the bolt.

24. The apparatus of claim 23, wherein the component extends into the first and second panels.

25. The apparatus of claim 24, wherein the first and second panels include holes and the component further comprises projections configured to form intermittent locating features.

26. The apparatus of claim 23, further comprising an adhesive injection channel extending from the head through the component.

27. A method, comprising:

additively manufacturing a first component; and

additively manufacturing a captive nut contained within the first component for interconnecting the first component to a second component.

28. The method of claim 27, wherein additively manufacturing the captive nut comprises co-printing the captive nut with the first component.

29. The method of claim 27, wherein additively manufacturing the captive nut comprises forming threads.

30. The method of claim 29, wherein forming threads comprises additively manufacturing threads.

31. The method of claim 27, wherein the captive nut is additively manufactured to float within the first component.

32. The method of claim 27, wherein the first component is additively manufactured to prevent the captive nut from rotating.

33. The method of claim 27, further comprising additively manufacturing a semi-spherical housing co-printed with the first component and the nut, wherein the nut is contained within the first component by the additively manufactured semi-spherical housing.

34. The method of claim 27, further comprising adding a shim which together with the first component forms a cavity and allows the nut to move along an axial axis of the nut.

35. The method of claim 34, wherein adding the shim comprises threading the shim to the first component.

36. The method of claim 27, further comprising forming an insert having a cavity, wherein the first component is engaged with the insert and the nut is contained within the cavity.

37. The method of claim 36, wherein additively manufacturing the first component includes forming an additively manufactured threaded portion and further comprising forming the insert to include a threaded insert engaged with the threaded portion of the first component.

38. The method of claim 36, further comprising adding a shim between a portion of the first component and the insert.

39. The method of claim 27, further comprising additively manufacturing a retainer plate which together with the first component forms a cavity, wherein the nut is contained within the cavity.

40. The method of claim 39, further comprising forming the retainer plate to be slid within a slot within the first component to install the captive nut and forming the retainer plate to slide out of the slot within the first component to retain the captive nut.

41. The method of claim 39, wherein the retainer plate is additively manufacturing the retainer plate to be rotatable between a first position to open the cavity to place the nut therein and a second position to lock the nut in the cavity.

42. The method of claim 39, further comprising forming at least one of a captive lug or a captive stud configured to facilitate the closing and releasing of the retainer plate.

43. The method of claim 27, wherein additively manufacturing the first component comprises additively manufacturing a node.

44. A method, comprising:

additively manufacturing a first component having a hole;

additively manufacturing a second component having a socket; and

forming a pin having a head engaging a surface of the first component and a shaft extending from the head through the hole in the first component and into the socket of the second component.

45. The method of claim 44, further comprising forming the pin to include an adhesive injection channel extending from the head through the shaft, the adhesive injection channel in communication with the hole the first component and a slot in the second component.

46. The method of claim 45, further comprising adding an adhesive extending through the adhesive injection channel of the pin and into the hole of the first component and the slot of the second component.

47. The method of claim 46, further comprising forming a seal between the first and second components to seal the adhesive in the hole of the first component and the slot of the second component.

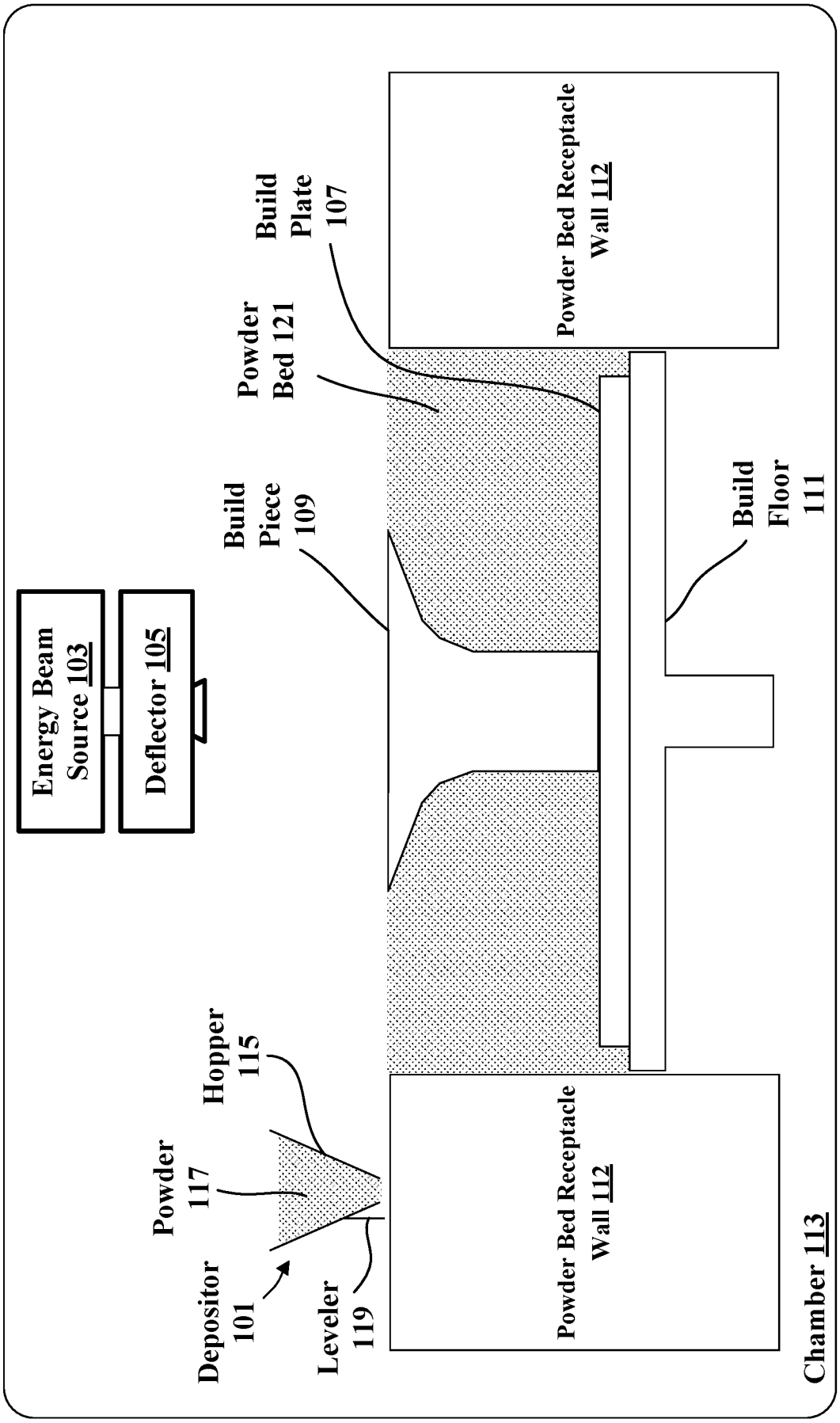

PBF System 100
Chamber 113
Powder Bed Receptacle Wall 112
Powder Bed Receptacle Wall 112
Build Plate 107
Powder Bed 121
Build Piece 109
Build Floor 111
Energy Beam Source 103
Deflector 105
Hopper 115
Powder 117
Depositor 101
Leveler 119

FIG. 1A

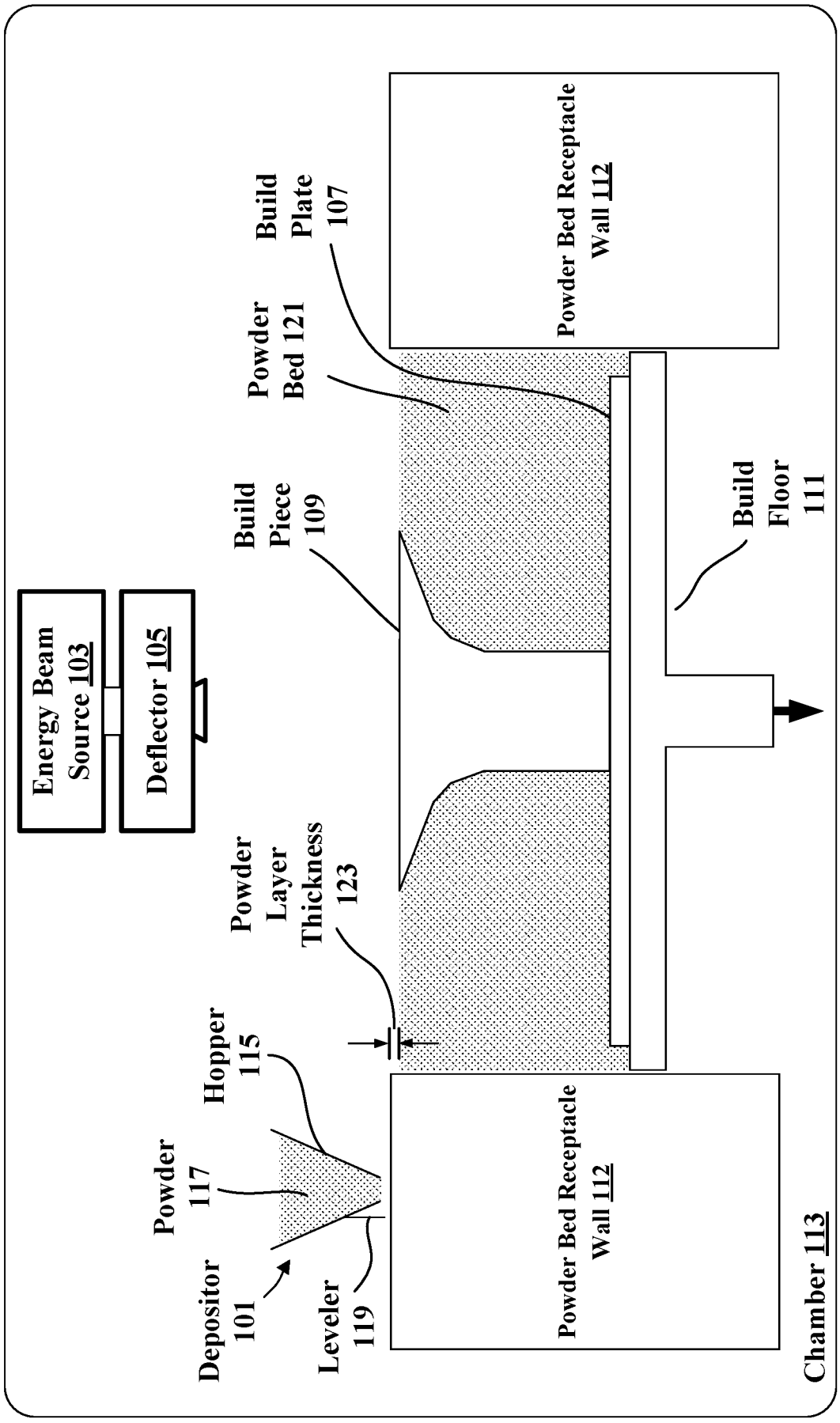

PBF System 100
Chamber 113
Powder Bed Receptacle Wall 112
Powder Bed Receptacle Wall 112
Build Floor 111
Build Piece 109
Build Plate 107
Powder Bed 121
Energy Beam Source 103
Deflector 105
Powder Layer Thickness 123
Hopper 115
Powder 117
Depositor 101
Leveler 119

FIG. 1B

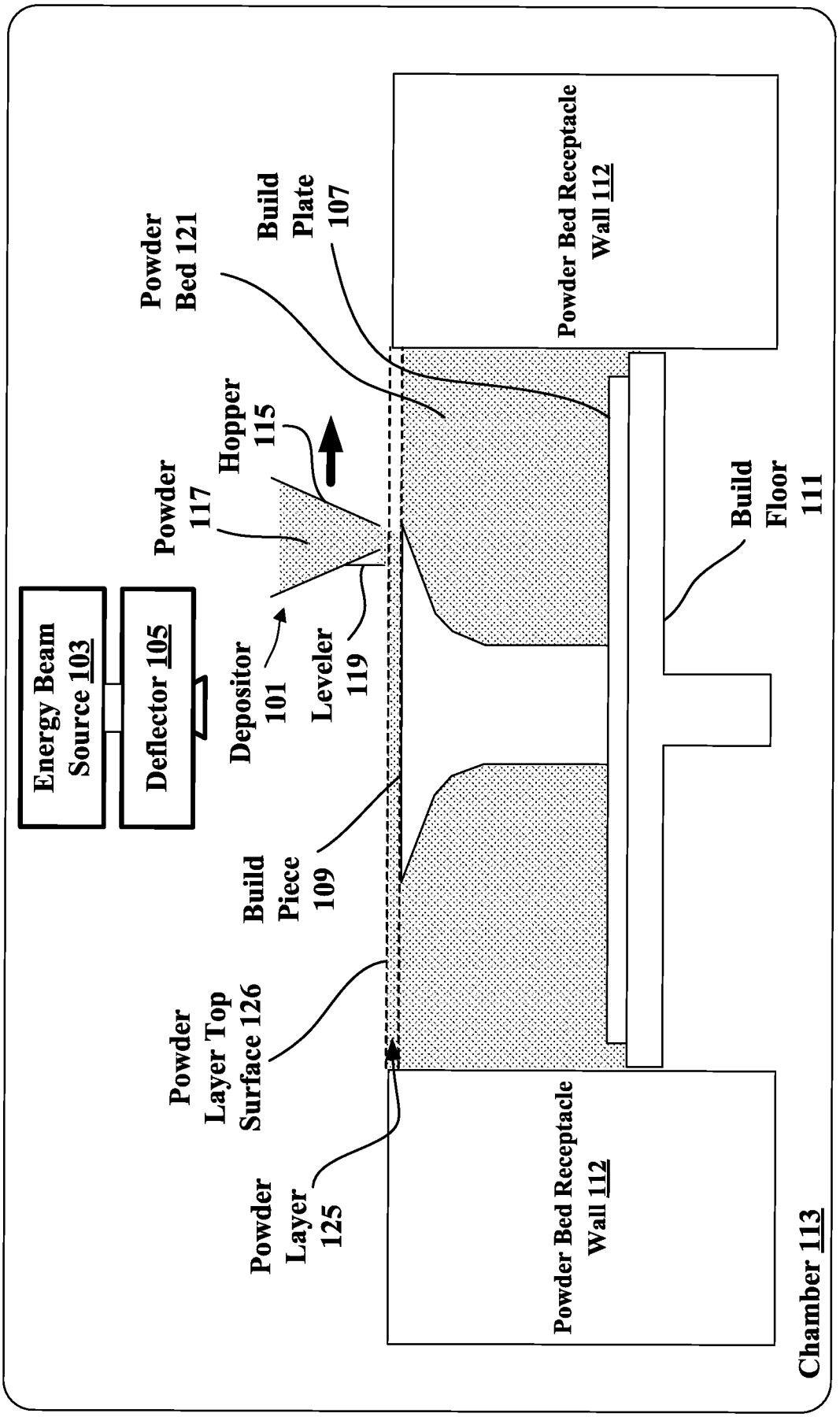

PBF System 100
Chamber 113
Powder Bed Receptacle Wall 112
Powder Bed Receptacle Wall 112
Build Floor 111
Build Plate 107
Powder Bed 121
Hopper 115
Powder 117
Energy Beam Source 103
Deflector 105
Depositor 101
Leveler 119
Build Piece 109
Powder Layer Top Surface 126
Powder Layer 125

FIG. 1C

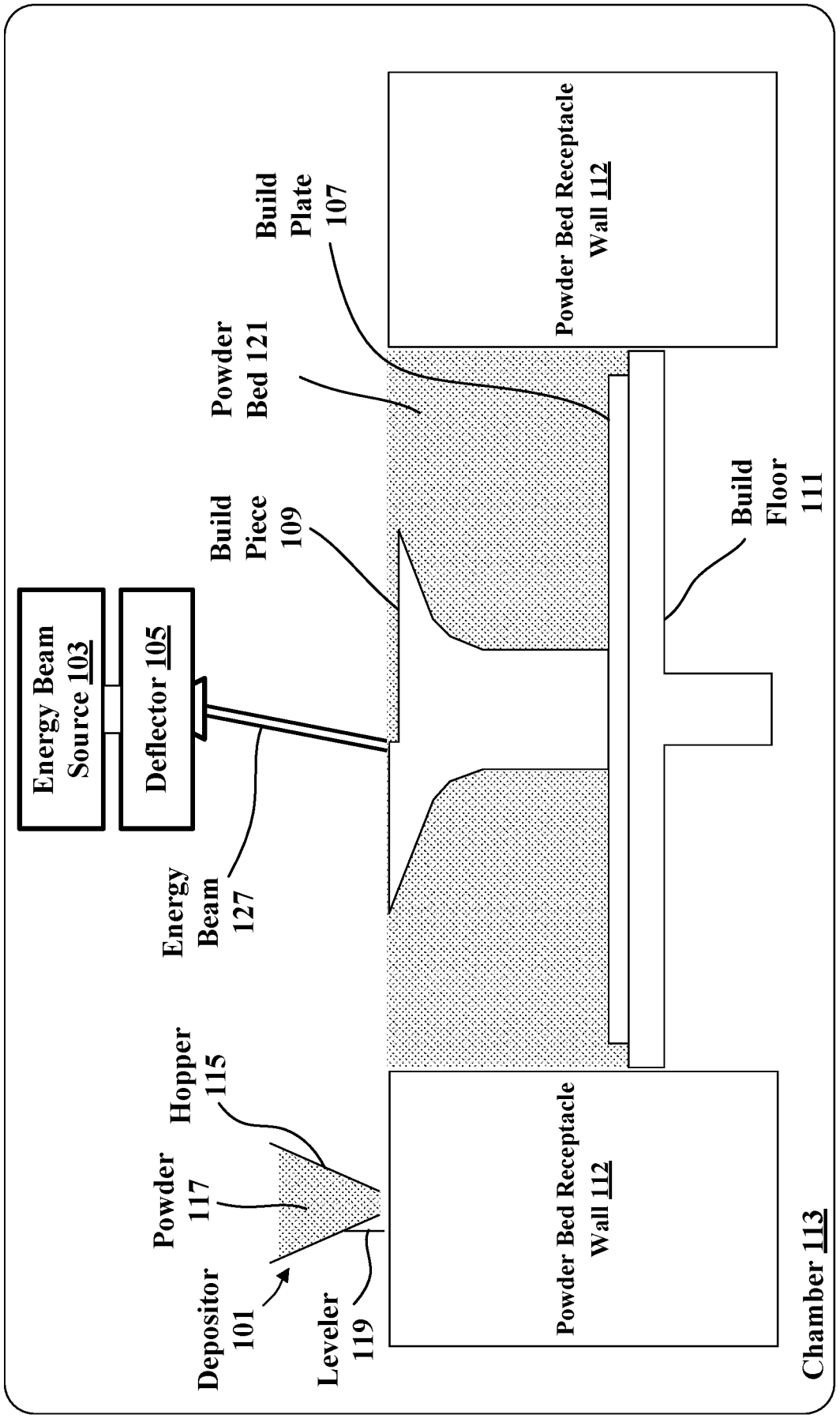
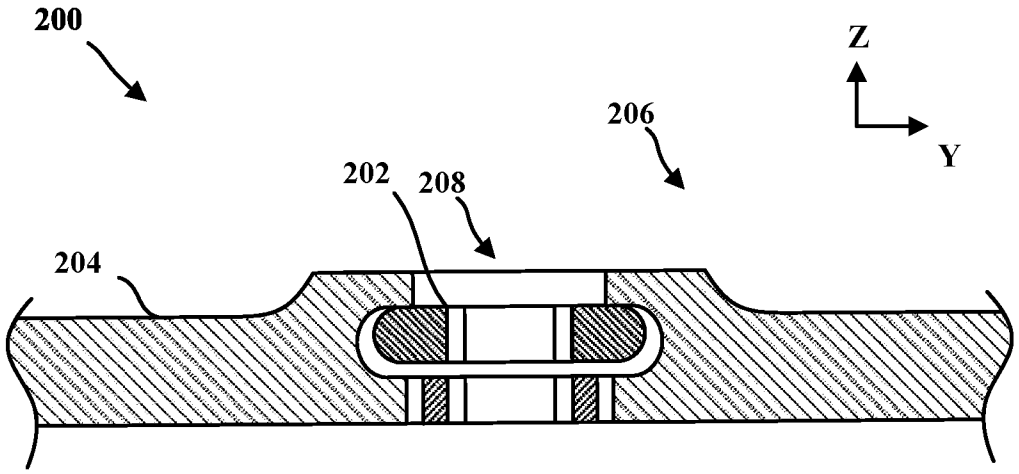
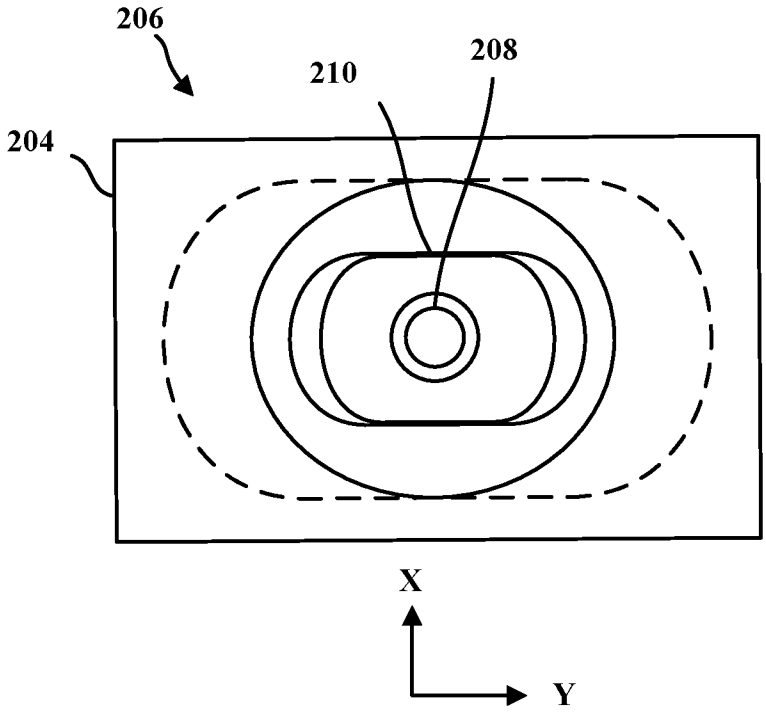

Energy Beam Source 103
Deflector 105
Energy Beam 127
Build Piece 109
Powder Bed 121
Build Plate 107
Powder Bed Receptacle Wall 112
Build Floor 111
PBF System 100
Hopper 115
Powder 117
Depositor 101
Leveler 119
Powder Bed Receptacle Wall 112
Chamber 113

FIG. 1D



(X-direction is into the page)

FIG. 2A



(Z-direction is out of the page)

FIG. 2B

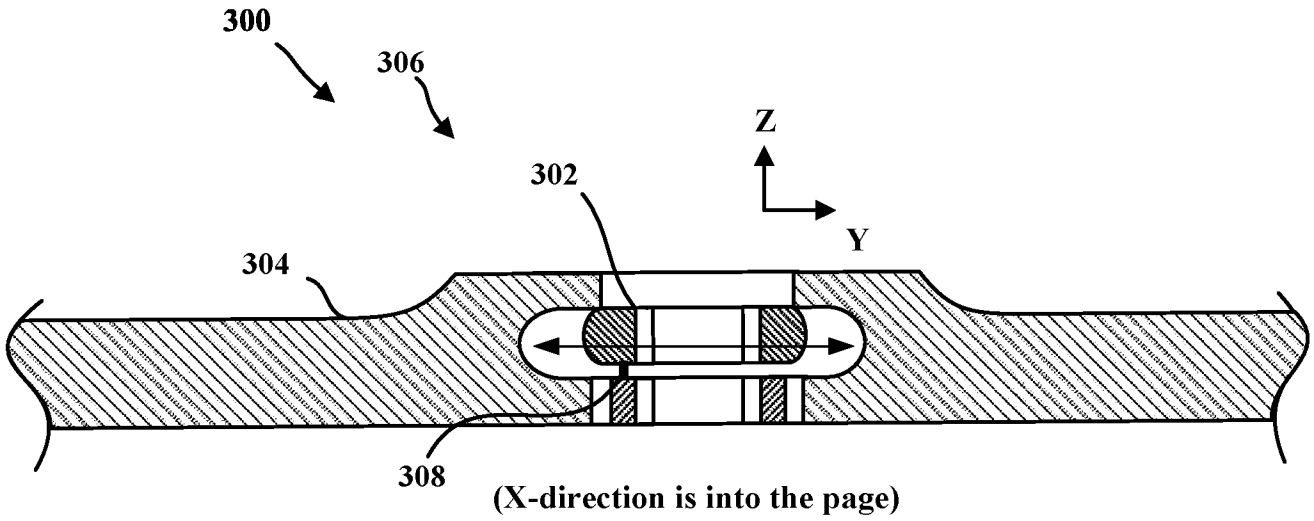


FIG. 3

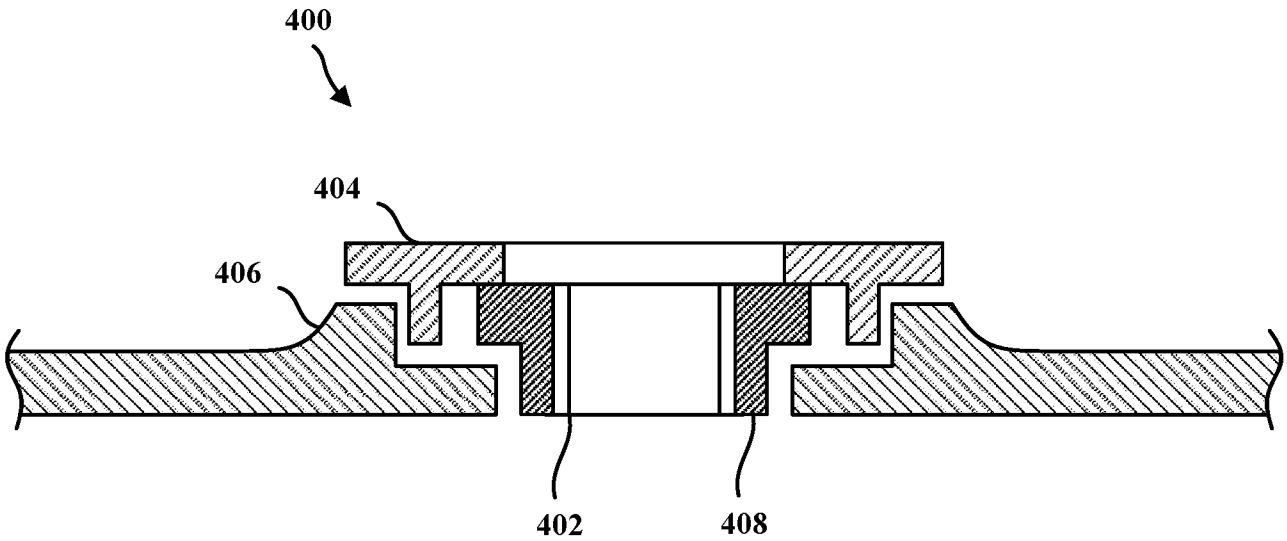


FIG. 4

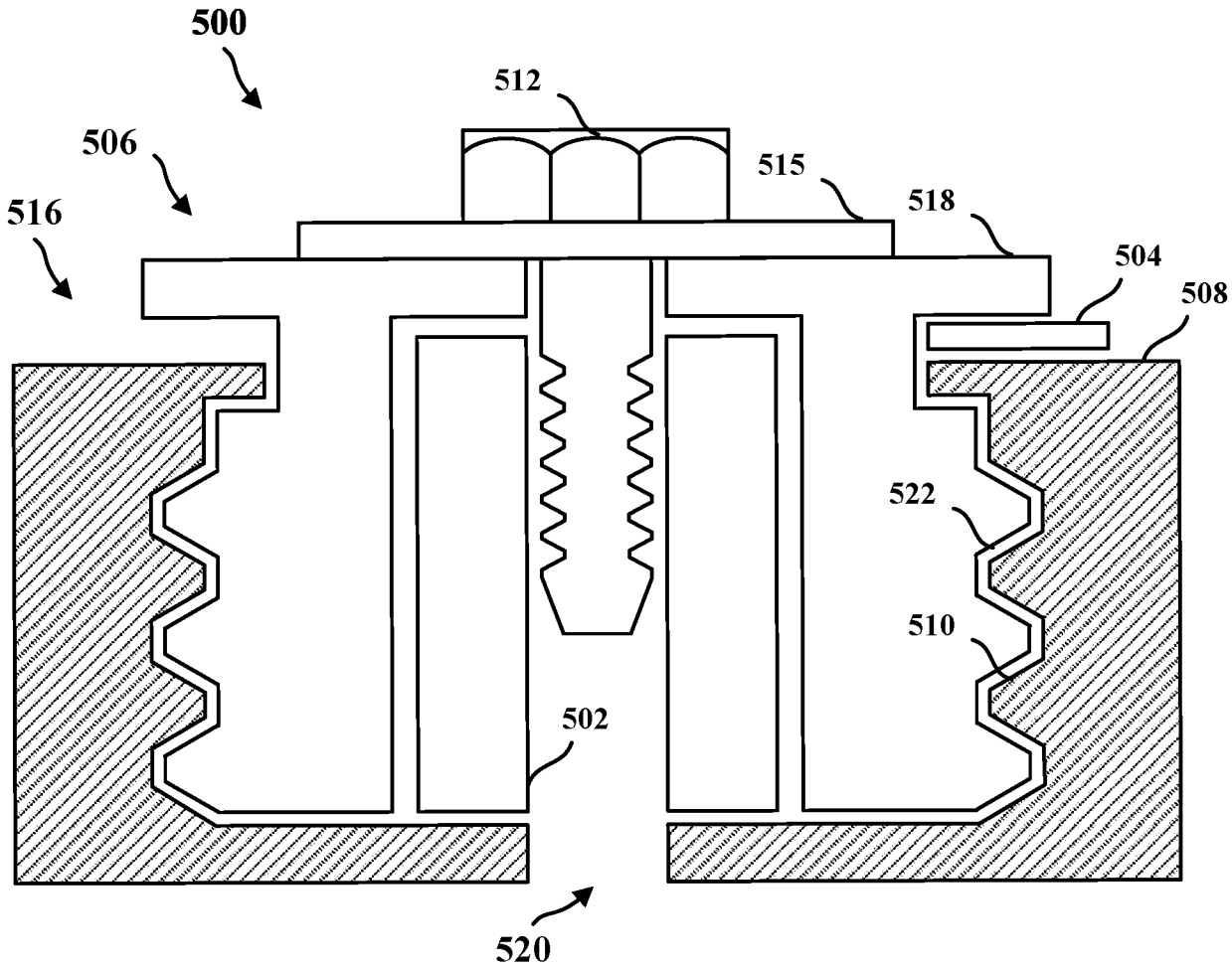


FIG. 5

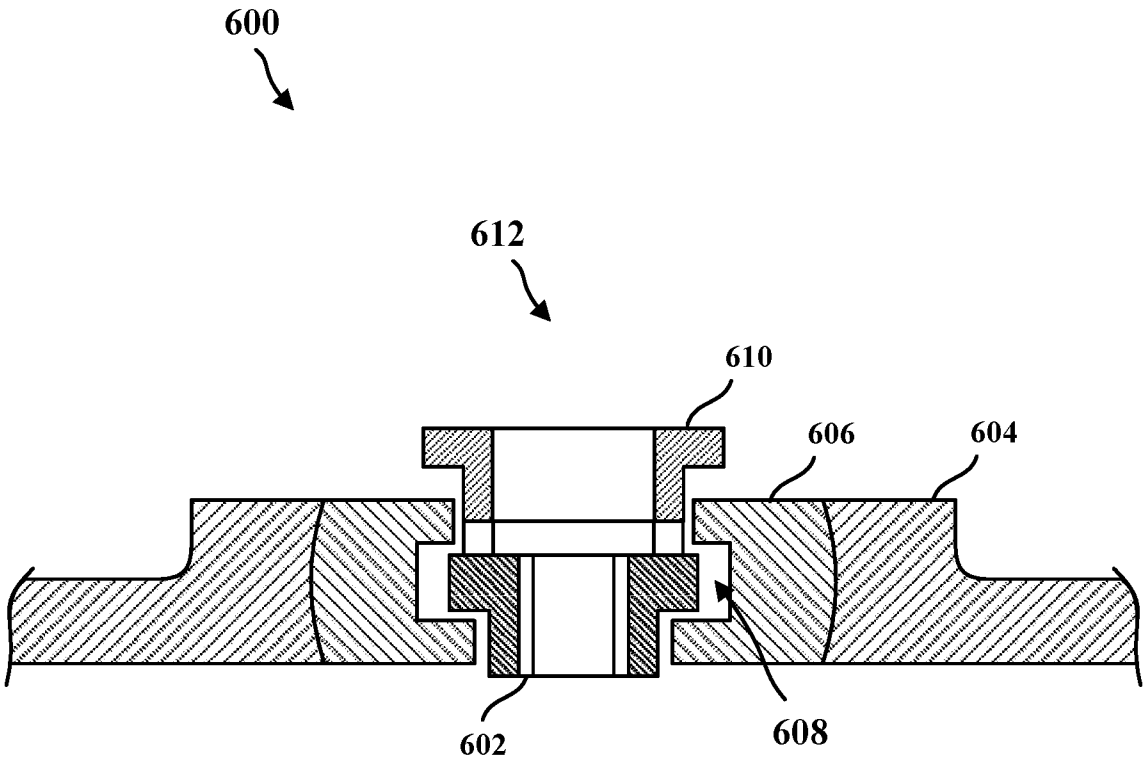


FIG. 6

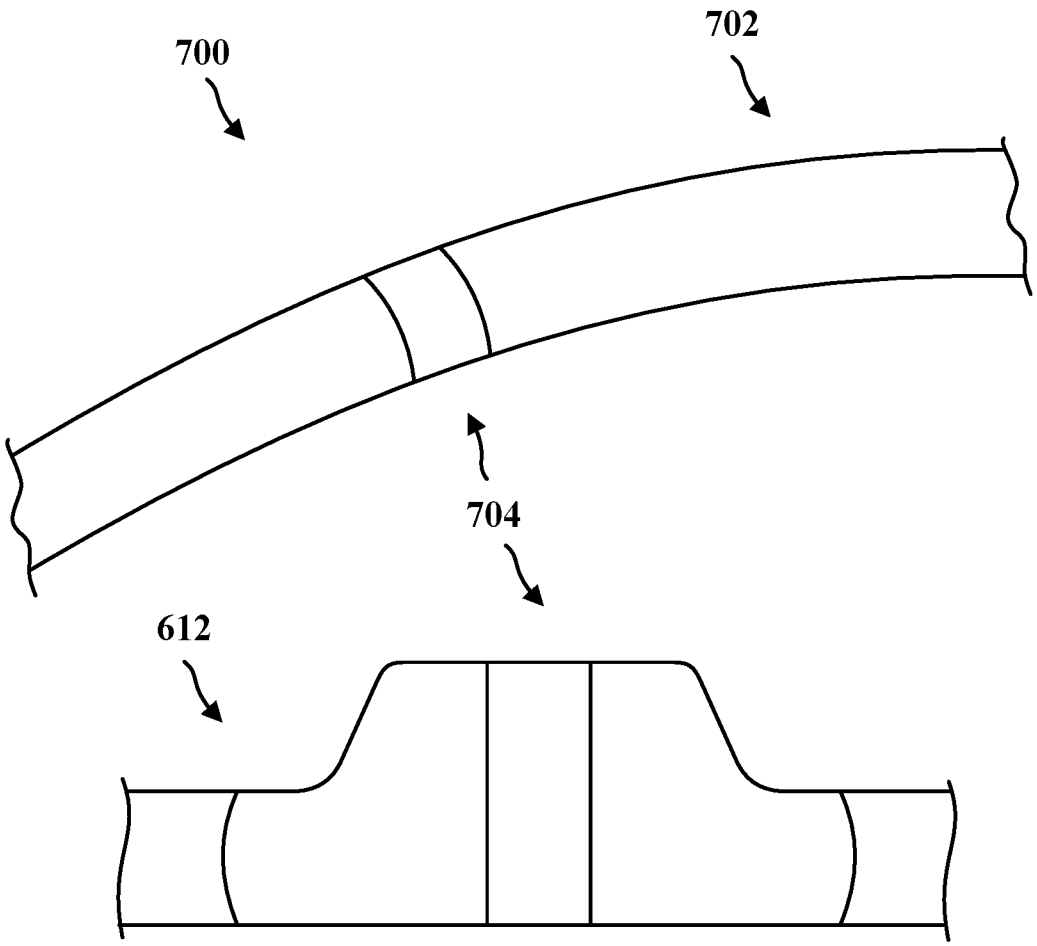


FIG. 7

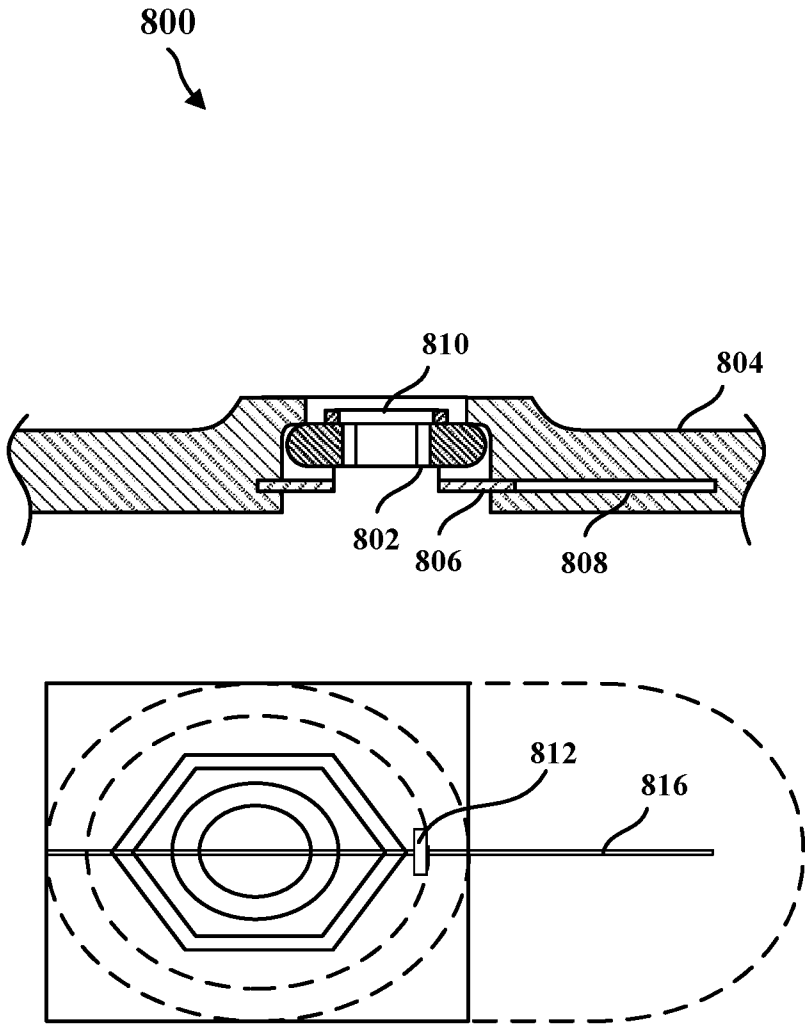


FIG. 8

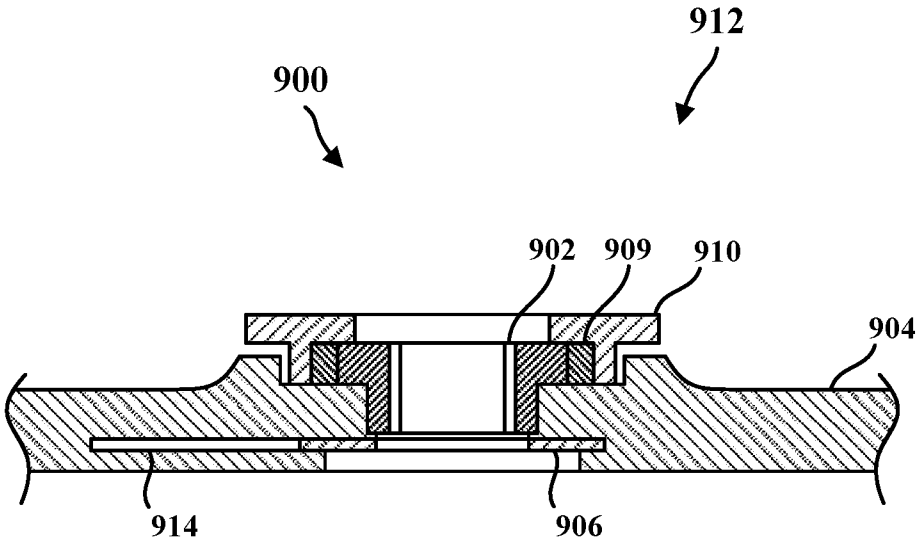


FIG. 9

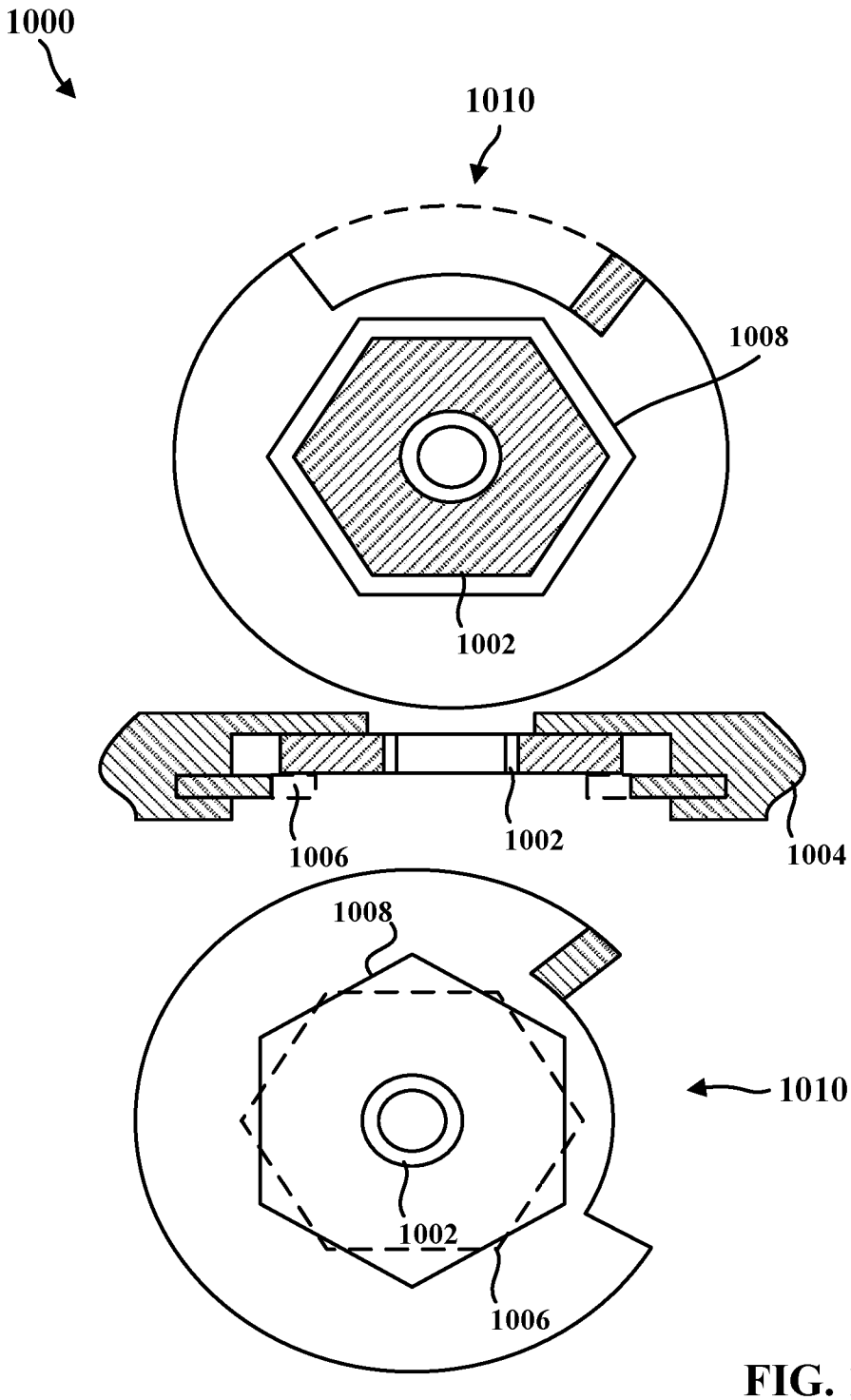


FIG. 10

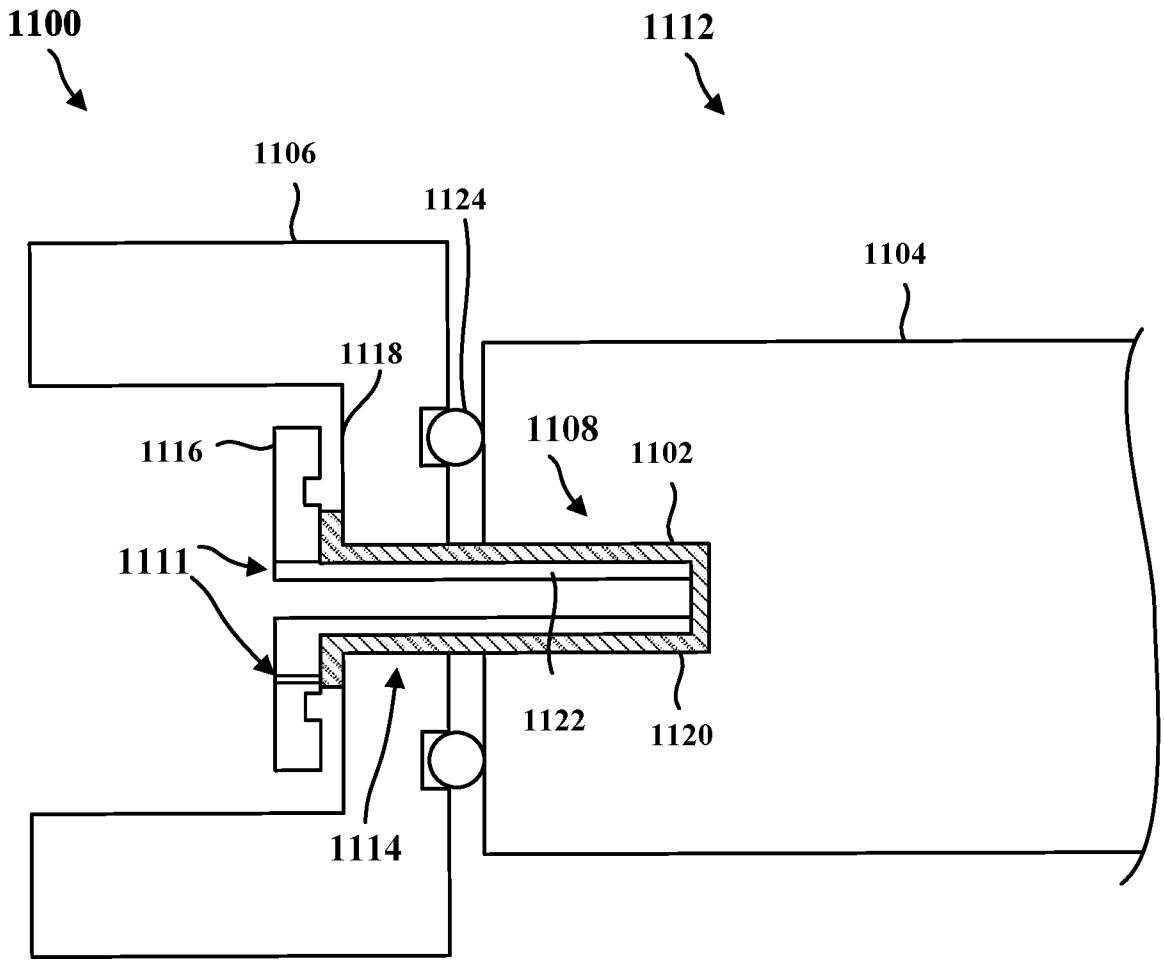

1100
1112
1106
1124
1104
1118
1116
1108
1102
1111
1122
1120
1114

FIG. 11

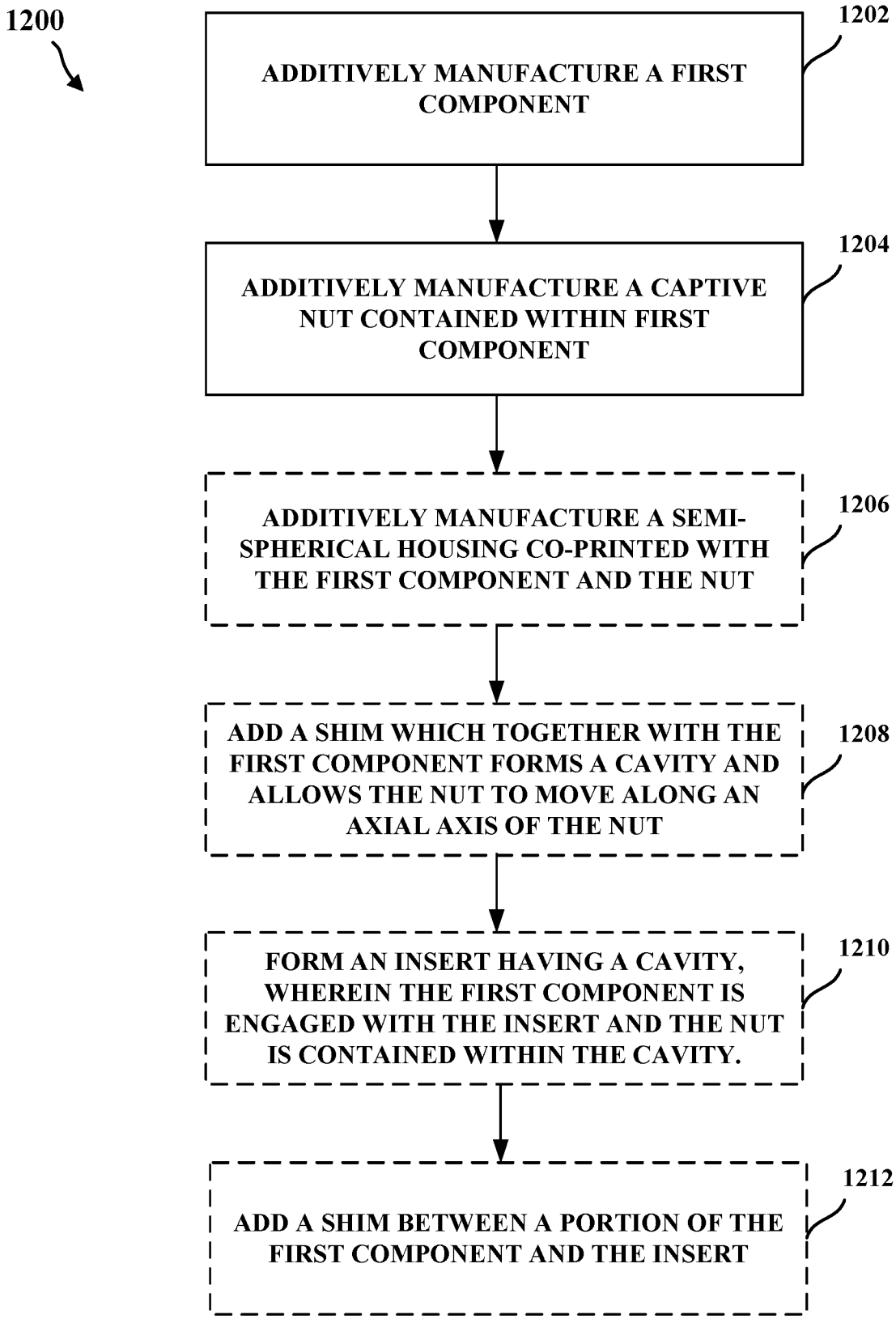

1200
ADDITIVELY MANUFACTURE A FIRST COMPONENT
1202
ADDITIVELY MANUFACTURE A CAPTIVE NUT CONTAINED WITHIN FIRST COMPONENT
1204
ADDITIVELY MANUFACTURE A SEMI-SPHERICAL HOUSING CO-PRINTED WITH THE FIRST COMPONENT AND THE NUT
1206
ADD A SHIM WHICH TOGETHER WITH THE FIRST COMPONENT FORMS A CAVITY AND ALLOWS THE NUT TO MOVE ALONG AN AXIAL AXIS OF THE NUT
1208
FORM AN INSERT HAVING A CAVITY, WHEREIN THE FIRST COMPONENT IS ENGAGED WITH THE INSERT AND THE NUT IS CONTAINED WITHIN THE CAVITY.
1210
ADD A SHIM BETWEEN A PORTION OF THE FIRST COMPONENT AND THE INSERT
1212

FIG. 12

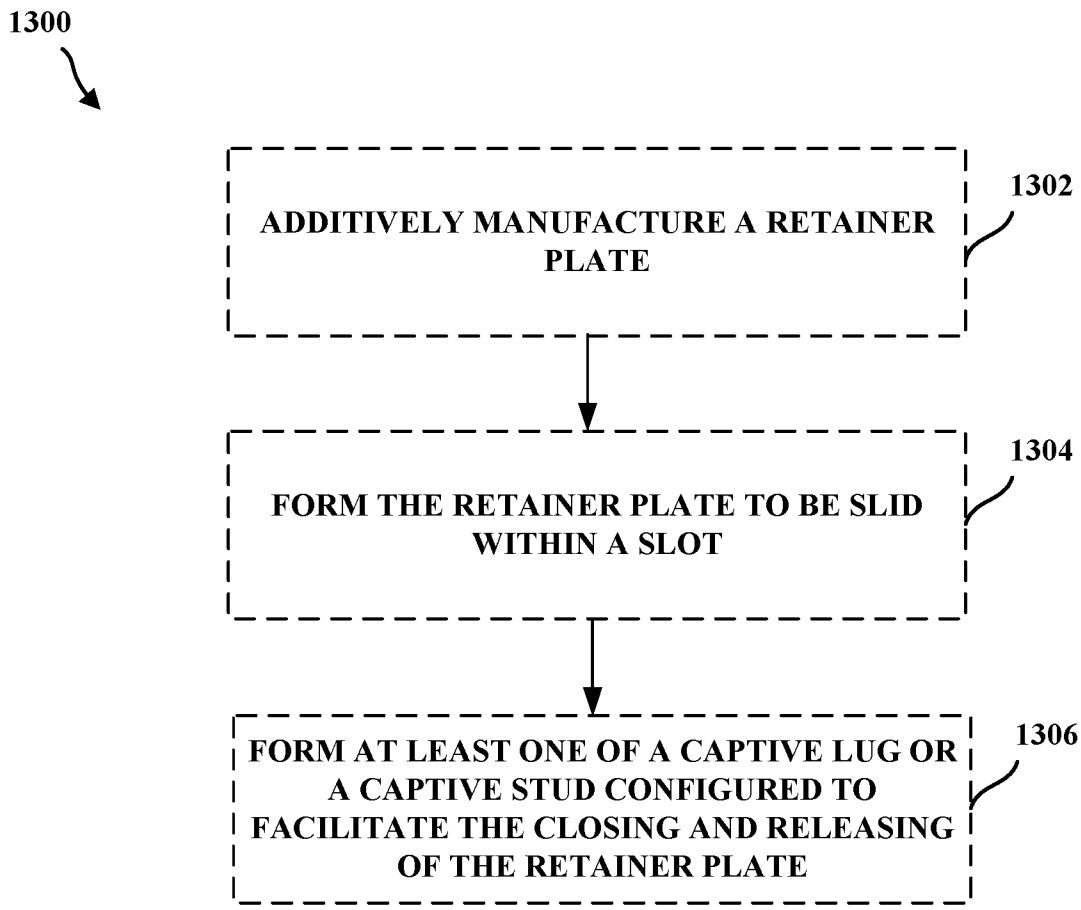

1300
ADDITIVELY MANUFACTURE A RETAINER PLATE
1302
FORM THE RETAINER PLATE TO BE SLID WITHIN A SLOT
1304
FORM AT LEAST ONE OF A CAPTIVE LUG OR A CAPTIVE STUD CONFIGURED TO FACILITATE THE CLOSING AND RELEASING OF THE RETAINER PLATE
1306

FIG. 13

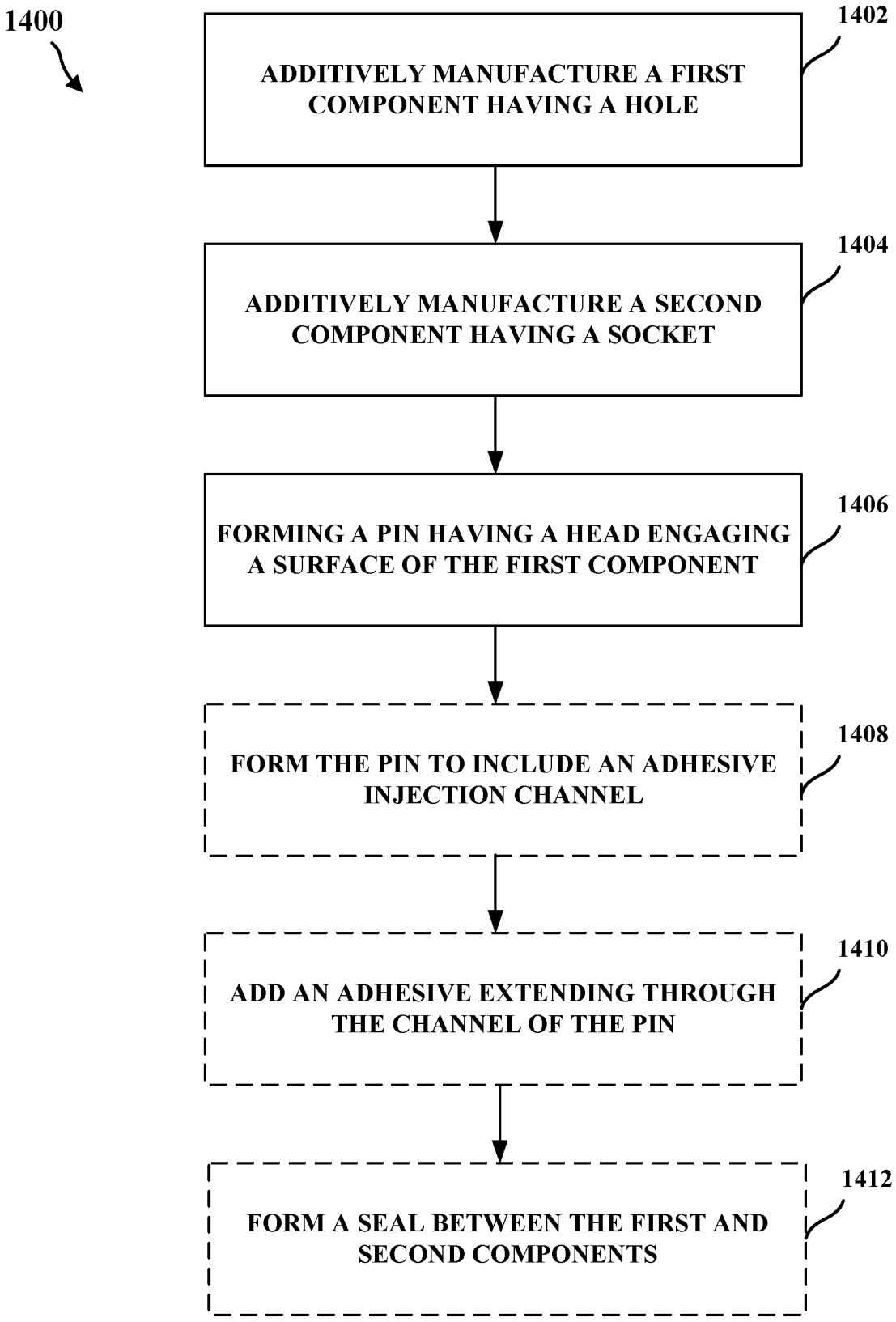

1400
ADDITIVELY MANUFACTURE A FIRST COMPONENT HAVING A HOLE
1402
ADDITIVELY MANUFACTURE A SECOND COMPONENT HAVING A SOCKET
1404
FORMING A PIN HAVING A HEAD ENGAGING A SURFACE OF THE FIRST COMPONENT
1406
FORM THE PIN TO INCLUDE AN ADHESIVE INJECTION CHANNEL
1408
ADD AN ADHESIVE EXTENDING THROUGH THE CHANNEL OF THE PIN
1410
FORM A SEAL BETWEEN THE FIRST AND SECOND COMPONENTS
1412

FIG. 14

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/038207

A. CLASSIFICATION OF SUBJECT MATTER

B22F 3/105(2006.01)i, B33Y 10/00(2015.01)i, B33Y 30/00(2015.01)i

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 3/105; B23K 26/00; B29C 65/00; E06B 1/00; E06B 3/00; F16B 1/00; F16B 13/04; F16B 37/04; B33Y 10/00; B33Y 30/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: additive manufacturing, captive nut, interconnect, first, second, shim, adhesive

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007-0051704 A1 (HUSMANN et al.) 08 March 2007 See paragraphs [0003], [0026]-[0028]; claim 1; and figures 2-3.	1-5,7,10-11,17-18,22-25,27-31,33,36-37,43-44
Y		6,8-9,12-16,19-21,26,32,34-35,38-42,45-47
Y	US 2009-0129885 A1 (CSIK et al.) 21 May 2009 See paragraph [0089]; and figures 1-3, 10, 15.	6,13-16,32,39-42
Y	US 2005-0047893 A1 (SCHWARZBICH, JORG) 03 March 2005 See paragraph [0041]; and figure 8.	8-9,12,21,34-35,38,47
Y	US 2007-0261787 A1 (MALIS, MICHAEL B.) 15 November 2007 See paragraphs [0019]-[0027]; and figures 1, 4.	19-21,26,45-47
A	WO 2015-147973 A1 (HRL LABORATORIES, L.L.C.) 01 October 2015 See paragraphs [0043]-[0047]; and figures 7-9.	1-47

☐ 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	Date of mailing of the international search report
28 September 2018 (28.09.2018)	**28 September 2018 (28.09.2018)**

Name and mailing address of the ISA/KR
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