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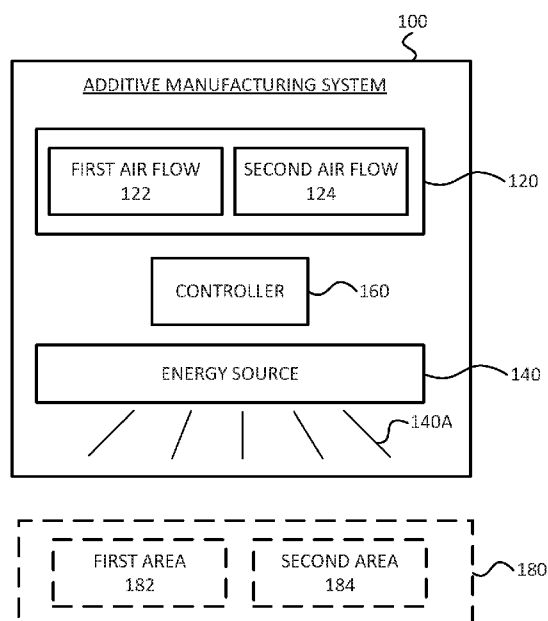


Fig. 1

(57) Abstract: An additive manufacturing system includes a cooling module to cause a first dominant air flow over a first print zone area and a second dominant air flow over a second print zone area. An energy source is to apply energy to the print zone. A controller is to (i) determine air flow characteristics by: controlling the cooling module to cause the first and second air flows to have respective first and second predetermined flow rates, controlling the energy source to apply energy to the print zone, and determining at least one of a parameter of the energy source and a characteristic of the first air flow and the second air flow. The controller is also to (ii) set at least one of the first and second air flow rates to be used during the processing of subsequent 3D printing operations based on the determined parameter or characteristic.

SETTING AIR FLOW RATES FOR 3D PRINTING

BACKGROUND

[0001] Additive manufacturing may comprise the operation of spreading additive manufacturing build material in a build material layer and printing or jetting an energy absorbing fusing agent over areas of successive layers of un-solidified build material to be fused, and applying a fusing energy to the build material layer to cause portions thereof on which fusing agent was printed to heat up, melt, coalesce, sinter, or fuse, and then solidify upon cooling.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] The present application may be more fully appreciated in connection with the following detailed description taken in conjunction with the accompanying drawings, in which like reference characters refer to like parts throughout and in which:

[0003] Fig. 1 is a block diagram illustrating an example of an additive manufacturing system to set air flow rates for 3D printing.

[0004] Fig. 2 is a block diagram illustrating an example of another additive manufacturing system to set air flow rates for 3D printing.

[0005] Fig. 3 is a block diagram illustrating an example of a cooling module to set air flow rates for 3D printing.

[0006] Fig. 4 is a block diagram illustrating an example of another additive manufacturing system to set air flow rates for 3D printing.

[0007] Fig. 5A is a block diagram illustrating an example of an energy source.

[0008] Fig. 5B is a block diagram illustrating another example of an energy source.

[0009] Fig. 6 is a block diagram illustrating another example of an additive manufacturing system to set air flow rates for 3D printing.

[0010] Fig. 7A is a schematic diagram illustrating an example of a calibration object.

[0011] Fig. 7B is a schematic diagram illustrating another example of a calibration object.

[0012] Fig. 8 is a flowchart of an example method for setting air flow rates for 3D printing.

[0013] Fig. 9 is a flowchart of another example method for setting air flow rates for 3D printing.

[0014] Fig. 10 is a block diagram illustrating an example of a processor-based system to set air flow rates for 3D printing.

DETAILED DESCRIPTION

[0015] The following description is directed to various examples of the disclosure. In the foregoing description, numerous details are set forth to provide an understanding of the examples disclosed herein. However, it will be understood by those skilled in the art that the examples may be practiced without these details. While a limited number of examples have been disclosed, those skilled in the art will appreciate numerous modifications and variations therefrom. It is intended that the appended claims cover such modifications and variations as fall within the scope of the examples. Throughout the present disclosure, the terms “a” and “an” are intended to denote at least one of a particular element. In addition, as used herein, the term “includes” means includes but not limited to, the term “including” means including but not limited to. The term “based on” means based at least in part on.

[0016] Additive manufacturing and/or three-dimensional (3D) printing may comprise the operation of spreading additive manufacturing build material in a build material layer and printing or jetting an energy absorbing fusing agent over areas of successive layers of un-solidified build material to be fused, and applying a fusing energy to the build material layer to

cause portions thereof on which fusing agent was printed to heat up, melt, coalesce, sinter, or fuse and then solidify upon cooling.

[0017] In the present disclosure, the term “fuse” shall be understood as fuse and/or melt, and/or coalesce, and/or sinter. For simplicity, terms “fuse”, “fusing”, and “to fuse” may be used throughout the disclosure.

[0018] Suitable powder-based build materials for use in examples herein include at least one of polymers, crystalline plastics, semi-crystalline plastics, polyethylene (PE), polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), amorphous plastics, polyvinyl alcohol plastic (PVA), polyamide, thermo(setting) plastics, resins, transparent powders, colored powders, metal powder, ceramics powder such as for example, glass particles, and/or a combination of at least two of these or other materials, wherein such combination may include different particles each of different materials, or different materials in a single compound particle. Example blended build materials include alumide, which may include a blend of aluminum and polyamide. As discussed above, some additive manufacturing systems use build material in, for example, a powdered or granular form. As described above, a suitable build material may be a powdered semi-crystalline thermoplastic material. A suitable material may be Nylon 12, which is available, for example, from Sigma-Aldrich Co. LLC. Another suitable material may be PA 2200 which is available from Electro Optical Systems EOS GmbH. According to another example, a suitable build material may be PA12 build material commercially known as V1R10A “HP PA12” available from HP Inc.

[0019] In other examples, other suitable build materials may be used. Such materials may include, for example, powdered metal materials, powdered plastics materials, powdered composite materials, powdered ceramic materials, powdered glass materials, powdered resin material, powdered polymeric materials, and the like. Different powders may have different characteristics, such as different average particle sizes, different minimum and maximum particle sizes, different coefficient of friction, different angle of repose, and the like. In some examples non-powdered build materials may be used such as gels, pastes, and slurries. Additionally, or alternatively from the above, in some examples build materials may be formed

from, or may include, short fibres that may, for example, have been cut into short lengths from long strands or threads of material.

[0020] In one example the build material is powder that has an average volume-based cross-sectional particle diameter size of between approximately 5 and approximately 400 microns, between approximately 10 and approximately 200 microns, between approximately 15 and approximately 120 microns or between approximately 20 and approximately 70 microns. Other examples of suitable, average volume-based particle diameter ranges include approximately 5 to approximately 70 microns, or approximately 5 to approximately 35 microns. In this disclosure a volume-based particle size is the size of a sphere that has the same volume as the powder particle. With “average” it is intended to explain that most of the volume-based particle sizes are of the mentioned size or size range but may also contain particles of diameters outside of the mentioned range. For example, the particle sizes may be chosen to facilitate distributing build material layers having thicknesses of between approximately 10 and approximately 500, or between approximately 10 and approximately 200 microns, or between approximately 15 and approximately 150 microns. One example of an additive manufacturing system may be a pre-set to distribute build material layers of approximately 80 microns using build material containers that contain powder having average volume-based particle diameters of between approximately 40 and approximately 70 microns. For example, the additive manufacturing apparatus can be configured to distribute different layer thicknesses.

[0021] A particular batch of build material that may be used in an additive manufacturing process may be either “fresh” build material, “recycled” build material, or a mix of the two. Fresh build material should be considered to be build material which has not previously been used in any part of an additive manufacturing process, and/or which has not passed through any part of the 3D printing system previously. In contrast, recycled build material may be considered as build material that has already been supplied to a 3D printing system for use in an additive manufacturing process. Not all of the build material supplied to a 3D printing system for use in additive manufacturing process may be incorporated into a 3D printed article. At least some of the unused build material supplied to a 3D printing system for use in an

additive manufacturing process may be suitable for reuse in a subsequent additive manufacturing process. Such build material is referred to as recycled build material.

[0022] Additive manufacturing systems, also known as three-dimensional (3D) printers, are devices to generate 3D printed objects. Additive manufacturing systems may generate 3D printed objects based on build material, for example the build material described above. The build material may be spread on a build platform forming a build bed. An example of build platform may be a substantially horizontal platform that is vertically movable within a build chamber.

[0023] An example additive manufacturing systems comprises a built-in build platform. However, in another example the build platform may be an element from a transportation unit that may be attached and detached from the additive manufacturing system. Some examples of transportation units may comprise wheels or any similar mechanism enabling the transportation unit to move freely, for example to allow the transportation unit to be connected to a build material processing unit to perform operations other than generate the 3D printed object. Some examples of the operations that may be performed by the build material processing unit may be: filling the transportation unit with build material, cooling down a transportation unit filled with build material, removing non-fused build material from a transportation unit, and the like. The transportation unit attachment and detachment from the additive manufacturing system and/or the build material processing unit may be performed by a user, or automatically with a transportation mechanism, for example, rails, engines, transportation belts and the like.

[0024] Some examples of additive manufacturing systems may include elements comprising physical asymmetries and irregularities therein. These asymmetries and irregularities may lead to non-uniform printing conditions on the printing zone of the build platform, e.g. different thermal conditions in the different locations of the print zone. Non-uniform printing conditions may lead to the generation of sub-quality 3D objects. For example, a printed part from a first area of the print zone may have a different print quality than another printed part from a second area of the print zone. An example of the object of the present disclosure may be

directed to address symmetrical thermal characteristics over a print zone to solve the above challenge.

[0025] Some additive manufacturing systems may apply fusing energy through at least one fusing lamp. In examples describe herein, the collection of locations that the fusing energy and printing agents may address may be referred as the “print zone”. The print zone may correspond to the whole surface area of the uppermost layer of build material formed on the build platform.

[0026] Other examples of additive manufacturing systems may apply fusing energy through a plurality of fusing lamps located above the build bed. Due to the physical location of the at least one fusing lamps of an additive manufacturing system, different sections of the upper layer of the build bed may not receive the same amount of energy. For example, sections around the edge of the build bed may receive less energy than the sections in the middle of the build bed. Thus, build material particles in the middle of the build bed may absorb a higher quantity of energy and fuse earlier than the build material particles around the edges of the build bed. This may lead to generated printed parts having different properties based on the location of the build bed in which said printed parts were located thereto. Some additive manufacturing systems comprise thermal sensors, e.g. thermal cameras and/or thermal point detectors, to monitor the temperature of different locations of the build bed. Where there is a thermal gradient between at least two different sections of the build bed, at least one fusing lamp may be controlled to modify its irradiation power so that substantially all location of the build bed are at substantially the same temperature

[0027] As used herein, the term “about”, “approximately”, and “substantially” are used to provide flexibility to a numerical range endpoint by providing that a given value may be, for example, an additional 20% more or an additional 20% less than the endpoints of the range. The degree of flexibility of this term can be dictated by the particular variable and would be within the knowledge of those skilled in the art to determine based on experience and the associated description herein.

[0028] Some additive manufacturing systems comprise a cooling module. A cooling module may, for example, comprise at least one cooling conduit that may comprise, for example, at least one fan. A cooling conduit is a cooling mechanism that supply at least one air flow to the print zone to help regulate the temperature of the print zone. For various design reasons, the cooling modules of some additive manufacturing systems may not be installed in a symmetrical manner with respect to the print zone, which may lead to the creation of asymmetrical air flows.

[0029] Examples described herein address asymmetrical thermal characteristics over a print zone through an additive manufacturing system calibration process. The calibration process may define operating parameters of one or multiple elements of an additive manufacturing system. After calibration, an additive manufacturing system may be used to generate 3D objects.

[0030] Referring now to the drawings, Fig. 1 is a block diagram illustrating an example of an additive manufacturing system 100 to set air flow rates for 3D printing. The additive manufacturing system 100 comprises a cooling module 120, an energy source 140, and a controller 160. The term “controller” as used herein may include a series of instructions encoded on a machine-readable storage medium and executable by a single processor or a plurality of processors. Additionally, or alternatively, a controller may include at least one hardware device including electronic circuitry, for example a digital and/or analog application-specific integrated circuit (ASIC), for implementing the functionality described herein.

[0031] The cooling module 120 may be any suitable mechanism to enable the system to mechanically generate at least one air flow to the print zone 180 of a print zone. Some examples of cooling module 120 comprise at least one cooling conduit located in the vicinity of the print zone 180. A cooling conduit may be referred to as a cooling tower. A cooling conduit may be an elongated enclosure through which warm air from the print zone may be evacuated to the exterior of the additive manufacturing system 100. In an example a cooling conduit comprises a fan. In one example the cooling conduit comprises a plurality of fans. Some examples of cooling module 120 comprise a plurality of cooling conduits located in the vicinity

of the print zone. The term “fan” may be interpreted as a powered machine used to create an air flow by, for example, rotating an assembly of blades. Depending on the direction of the rotation of the assembly of blades, a fan may cause an air flow from outside of the additive manufacturing system 100 to the print zone 180 or may cause an air flow from the print zone 180 to outside of the additive manufacturing system.

[0032] In the present disclosure, the print zone 180 may be divided in a plurality of areas. In an example, the print zone 180 may be divided into two areas of substantially the same surface area. In the example, the two areas may be referred hereinafter as the first area 182 and the second area 184. For simplicity, the examples of the present disclosure make reference to the first area 182 and the second area 184, however the print zone 180 may be divided into any other quantity of areas.

[0033] The cooling module 120 is to cause a first dominant air flow 122 in a first dominant direction over the first area 182 of the print zone 180 and to cause a second dominant air flow 124 in a second dominant direction over the second area 184 of the print zone 180. The cooling module 120 may generate the first dominant air flow 122 and the second dominant air flow 124 so that hot air from the print zone 180 is evacuated outside of the additive manufacturing system, thereby cooling down the print zone 180. In an example, the cooling module 120 comprises a first cooling conduit comprising a first fan, or group of fans, to generate the first dominant air flow 122, and a second cooling conduit comprising a second fan, or group of fans, to generate the second dominant air flow 124. In yet another example, the first dominant air flow 122 and the second dominant air flow 124 may be controlled by an external fan system, i.e. that is not part of the additive manufacturing system 100, where the controller 120 may provide a control signal to control the external fan system.

[0034] The energy source 140 is to apply energy 140A to the build material in the print zone 180. In normal operation the energy source 140 is to cause a solidification of portions of the build material, for example to portions to which an agent, e.g., a fusing agent, has been delivered or has penetrated. In some examples, the energy source 140 is an infra-red (IR) radiation source, a near infra-red radiation source or a halogen radiation source. In some

examples, the energy source 140 applies energy in a substantially uniform manner to the whole surface of a layer of build material, and a whole layer may have energy applied thereto simultaneously, which may increase the speed at which a three-dimensional object may be generated. In other examples, the energy source 140 applies energy in a substantially uniform manner to a portion of the whole surface of a layer of build material. For example, the energy source 140 may apply energy to a strip of the whole surface of a layer of build material. In these examples the energy source 140 may be moved or scanned across the layer of build material such that a substantially equal amount of energy is ultimately applied across the whole surface of a layer of build material. In some examples, the energy source 140 may be mounted on a moveable carriage. In other examples, the energy source 140 may apply a variable amount of energy as it is moved across the layer of build material, for example in accordance with agent delivery control data. For example, the controller 160 may control the energy source 140 to apply energy to portions of build material on which fusing agent has been applied.

[0035] According to an example, a suitable fusing agent may be an ink-type formulation comprising carbon black, such as, for example, the fusing agent formulation commercially known as V1Q60A “HP fusing agent” available from HP Inc. In one example such a fusing agent may additionally comprise an infra-red light absorber. In one example such an ink may additionally comprise a near infra-red light absorber. In one example such a fusing agent may additionally comprise a visible light absorber. In one example such an ink may additionally comprise a UV light absorber. Examples of inks comprising visible light enhancers are dye based colored ink and pigment based colored ink, such as inks commercially known as CE039A and CE042A available from HP Inc.

[0036] The controller 160 is to determine the first air flow 122 and the second air flow 124 calibration characteristics, and to set the cooling module 120 to the determined characteristics to be used during the processing of subsequent 3D printing operations to generate a 3D object.

[0037] During the calibration process, the controller 160 is to control the cooling module 120 to cause a first air flow 122 to have a first predetermined flow rate. The controller 160 is also to control the cooling module 120 to cause a second air flow 124 to have a second predetermined

flow rate. In some examples, the first predetermined flow rate and the second predetermined flow rate may be different flow rates. In other examples, the first predetermined flow rate and the second predetermined flow rate may be the same flow rate. The controller 160 may select the first predetermined flow rate and the second predetermined flow rate based on an input from a user. The user may manually enter the values of the first and second predetermined flow rates through a control panel attached that, in some cases, may be attached to the system 100. In other examples, the controller 160 may select the first and second predetermined flow rates through machine learning techniques or based on a pre-defined look-up table (LUT).

[0038] During the calibration process, the controller 160 is also to control the energy source 140 to apply energy 140A to the print zone 180. A portion of the energy 140A applied by the energy source 140 may be absorbed by build material present in the print zone, therefore increasing the temperature of the build material therein. Due to the asymmetries of the system 100 described above, the different areas of the print zone 180, e.g., first area 182 and the second area 184, may absorb a different amount of energy, therefore leading to a non-uniform temperature print zone.

[0039] During the calibration process, the controller 160 is further to determine a parameter of the energy source 140. In other examples, the controller is also to determine a characteristic of the first air flow 122 and the second air flow 124. In yet other examples, the controller 160 is to determine a parameter of the energy source 140 and a characteristic of the first air flow 122 and the second air flow 124. An example of a characteristic of the first air flow 122 and the second air flow 124 may be the difference of temperature, i.e. temperature gradient, from the first air flow 122 and the second air flow 124. An example of a parameter of the energy source 140 may be the energy consumption of the energy source 140.

[0040] Based on the previous determination, the controller 160 is to set at least one of the first air flow rate, and the second air flow rate to be used during the processing of subsequent 3D printing operations. In an example, the controller 160 may determine that the determination indicates that the air flow conditions lead to acceptable thermal print zone 180 conditions to generate 3D objects. In other examples, the controller 160 may perform the same operations

with a different first flow rate value and/or a different second flow rate value and determine which of the first air flow rate and second air flow rate values lead to better thermal print zone 180 conditions with which to generate 3D objects. In additional examples, the controller 160 repeatedly performs the same operations with different first flow rate values and/or different second flow rate values, until an acceptable thermal print zone 180 conditions are reached. The first air flow 122 and second air flow 124 conditions that lead to better thermal print zone 180 conditions are set as to be used during the processing of subsequent 3D printing operations.

[0041] Fig. 2 is a block diagram illustrating an example of another additive manufacturing system 200 to set air flow rates for 3D printing. The additive manufacturing system 200 may comprise a cooling module 220, an energy source 240, a controller 260, and a layering module 250. The cooling module 220, and the energy source 240 may be the same as or similar to the cooling module 120, and the energy source 140, of Fig. 1. The controller 260 may be to perform at least the same operations as controller 160 from Fig. 1.

[0042] The layering module 250 may be any mechanism to supply the print zone with a build material layer. In an example the layering module may be a roller to spread build material in a layer in the print zone. The layering module 250 may supply layers of substantially the same thickness. In some examples, the thickness from each of the build material layers may range from about 80 microns to about 120 microns. However, the thickness of a build material layer may be bigger or smaller.

[0043] The controller 260 may be further to control the layering module 250 to supply a plurality of sets of build material layers. In an example, the controller 260 may control the layering module 250 to supply a first set of build material layers 280A. The controller 260 may control the layering module 250 to supply a second set of build material layers 280B. The controller 260 may control the layering module 250 to supply a third set of build material layers 280C. And the controller 260 may control the layering module 250 to supply a fourth set of build material layers 280D. The print zone of each of set of build material layers may comprise a plurality of areas, for example, the fourth set of build material layers may comprise a first area 280D1 and a second area 280D2.

[0044] The controller 260 may perform the operations of the controller 160 from Fig. 1 in each of the sets of build material layers, as described above. For example, the controller 260 is to control the cooling module 220 to modify the air flow rate of at least one of the first air flow and the second air flow. By modifying the air flow rate of the first air flow and/or the second air flow, the thermal conditions on the print zone may be different in each of the sets of build material layers. The controller 260 is also to determine at least one of a parameter of the energy source, and/or a characteristic of the first air flow and the second air flow (see, e.g., Fig. 4) in each of the pluralities of build material layers 280A-280D. The controller 260 may further set the first air flow rate and the second air flow rate to be used during the processing of subsequent 3D printing operations as the pair of air flow rate values that lead to the best thermal conditions of the respective print zone areas. In the example, the controller 260 had four pairs of air flow rate values to pick from, i.e. one pair of air flow rates for each of the set of build material layers generated 280A-280D. In the example, four sets of build material layers have been used, however any other amount of pluralities of build material layers may be used without departing from the scope of the present disclosure.

[0045] As described above, in some examples, the values of the first air flow rate and the second air flow rate may be selected based on user input through a UI, or a LUT. In another example, the values of the first air flow rate and the second air flow rate may be selected through machine learning techniques. In the machine learning techniques example, the controller 160 may use statistical techniques to learn about the thermal conditions of the print zone based on the first flow rate and the second flow rate. Then, the controller 260 may automatically predict a more accurate first flow rate value and second flow rate value to perform the functionality of the controller 160 from Fig. 1.

[0046] Fig. 3 is a block diagram illustrating an example of a cooling module 320 to set air flow rates for 3D printing. The cooling module 320 may be an example implementation of the cooling module 120 from Fig. 1. The cooling module 320 comprises a first cooling mechanism 325 and second cooling mechanism 326. Additionally, or alternatively, the cooling module 320 may have a cooling adjusting mechanism 327 coupled to the first cooling mechanism 325 and

the second cooling mechanism 326. The cooling adjusting mechanism 327 may be coupled to a controller (not shown).

[0047] The first cooling mechanism may be any mechanism, device, or group of devices that can cause an air flow. The first cooling mechanism 325 is to cause the first air flow 322 over a first area 382. The first air flow 322 is illustrated as an arrow indicating the direction of the first air flow. The first air flow 322 takes hot air from the first area 328 to the outside of the system the cooling module 320 is installed in, e.g. the additive manufacturing system 100 from Fig. 1. By taking out hot air from the first area 382, the first cooling mechanism 325 cools down the first area 382. The first area 382 may be a subset of the printing zone 380. The first area 382 may be the same area or a similar area as the first area 182 shown in Fig. 1. The second cooling mechanism 326 may a similar mechanism than the first cooling mechanism 325 to cause the second air flow 324 over the second area 384.

[0048] The cooling adjusting mechanism 327 may be any mechanism to adjust the flow rate of the first air flow 322. The cooling adjusting mechanism 327 may be also to adjust the flow rate of the second air flow 324. In an example, the cooling adjusting mechanism 327 may adjust the difference of flow rate between the first flow rate and the second flow rate.

[0049] In an example, the cooling adjusting mechanism 327 may adjust the first cooling mechanism 325 and the second cooling mechanism 326 so that the first flow rate and the second flow rate take different flow rate values with respect to each other. In some examples, the flow rate values may be the same flow rate values. In other examples, the first flow rate may be a multiple of the second flow rate. In yet other examples, the second flow rate may be a multiple of the first flow rate.

[0050] The cooling module 320 may be coupled with a controller (not shown). The controller may be an internal built-in controller within the cooling module or the controller of the system the cooling module is installed in. The controller may be the same as or similar to the controller 160 from Fig. 1. In an example, the controller is to control the cooling adjustment mechanism 327 to adjust at least one of the first flow rate and the second flow rate based on at least one of the determined parameter (see, e.g., Fig. 5) and characteristic (see, e.g., Fig. 4). In another

example, the controller is to control the first cooling mechanism 325 and/or the second cooling mechanism 326 to adjust the first flow rate and the second flow rate based on at least one of the determined parameter and characteristic.

[0051] Fig. 4 is a block diagram illustrating an example schematic side view of another additive manufacturing system 400 to set air flow rates for 3D printing. The additive manufacturing system 400 comprises a cooling module comprising at least a first cooling conduit 425 and a second cooling conduit 426. The system 400 also comprises an energy source 440 and a controller 460. The energy source 440 may be the same as or similar to the energy source 140, of Fig. 1. The controller 460 may be to perform at least the same operations as controller 160 from Fig. 1.

[0052] The first cooling conduit 425 and the second cooling conduit 426 may comprise any shape to enable an air flow to flow therethrough. In the illustrated example, the first cooling conduit 425 and the second cooling conduit 426 are elongated prism or cylinder with an air flow channel inside.

[0053] The first cooling conduit 425 comprises a first cooling mechanism 425A, and the second cooling conduit 426 comprises a second cooling mechanism 426A. The first cooling mechanism 425A may comprise any mechanism, device, or group of devices that can cause an air flow. The first cooling mechanism 425A and the second cooling mechanism 426A may comprise a single or a plurality of fans installed in the elongated length of the first cooling conduit 425. The amount of fans within the first cooling mechanism 425A may not be the same amount of fans as the amount of fans in the second cooling mechanism 426A. In the illustrated example, the first cooling mechanism 425A and the second cooling mechanism 426A are placed on the walls of the first cooling conduit 425 and the second cooling conduit 426 respectively. However, these placements are drawn as such for clarity reasons and, in other examples, the placements may differ, for example, within their respective cooling conduits orthogonally oriented with respect to the elongated vertical axis of the conduits.

[0054] In some examples, the first cooling mechanism 425A may be to cause a first dominant air flow 422 over a first area 482 of a print zone 480. The second cooling mechanism 426A may

be to cause a second dominant air flow 424 over the second area 484 of the print zone. The first dominant air flow 422 and the second dominant air flow 424 are illustrated as arrows wherein the direction of the arrow is intended to point the direction of the air flow. Precisely, the first cooling module 425A and the second cooling module 426A are to evacuate hot air from the first area 482 and the second area 484 respectively, therefore cooling down the print zone 480. The print zone 480, the first area 482, and the second area 484 may be the same elements as the print zone 180, the first area 182, and the second area 184 from Fig. 1.

[0055] In an example, a first temperature sensor 455 may be installed on an inner wall of the first cooling conduit 425 and may be to measure the temperature of the first air flow 422. In the example, a second temperature sensor 456 may be installed on an inner wall of the second cooling conduit 426 and may be to measure the temperature of the second air flow 424. The first temperature sensor 455 and the second temperature sensor 456 may be any suitable gas temperature sensor. The first temperature sensor 455 and the second temperature sensor 456 may be coupled to the controller 460.

[0056] The controller 460 may be to obtain a temperature of the first air flow 422 and the second air flow 424. As an example, the controller 460 may obtain the temperature of the first air flow 422 from the first temperature sensor 455 and may obtain the temperature of the second air flow 424 from the second temperature sensor 456. The controller 460 may be to determine the difference between the temperature of the first air flow 422 and the temperature of the second air flow 424.

[0057] The controller 460 may be to determine the characteristic based on a difference of temperature between the first air flow and the second air flow. Based on this determination, the controller 460 is to set at least one of the first air flow rate, and the second air flow rate to be used during the processing of subsequent 3D printing operations.

[0058] Fig. 5A is a block diagram illustrating an example of an energy source 500A. The energy source 500A may be the same energy source or a similar energy source as the energy source 140 from Fig. 1. The energy source 500A comprises an array of energy sources comprising a first

energy emitter 525A and a second energy emitter 545A. The energy source 500A may be placed above and in a substantially parallel orientation with respect to a build platform.

[0059] The first energy emitter 525A is to apply energy to a first area of a print zone (not shown). The first area of the print zone may be the same area or a similar area as the first area 182 shown in Fig. 1. Likewise, the second energy emitter 545A is to apply energy to a second area of the print zone (not shown). The second area of the print zone may be the same area or a similar area as the second area 184 shown in Fig. 1.

[0060] In an example, the energy emitted by the energy emitters from the energy source 500A may comprise energy beams that travel substantially orthogonally with respect to the energy source 500A plane. In the described example, substantially the entirety of the energy emitted by the energy emitters is received by the respective print area of the print zone. In another example, the energy emitter from the energy source 500A may emit energy beams that may not travel substantially orthogonally with respect to the energy source 500A plane.

[0061] As an example, the energy source 500A may also comprise a temperature sensor 560A to determine a temperature profile of the first area and the second area. In other examples, the temperature sensor 560A may be an external element not included in the energy source 500A. In the present disclosure, the term “temperature profile” should be understood as a thermal mapping from a plurality of the locations of a print zone that indicates, at the resolution of the temperature sensor 560A, the temperature of the plurality of the locations. An example of a temperature sensor 560A may be a thermal camera. Thermal cameras may be commercially available in different resolutions, for example, 30 dots-per-inch. Another example of a temperature sensor 560 may be a point sensor which measures the temperature of the location in the print zone the sensor is pointing to.

[0062] The energy source 500A may be coupled to a controller (not shown). In an example, the controller may also be coupled to the temperature sensor 560A. The controller may be to perform at least the same operations as controller 160 shown in Fig. 1. The controller may control the temperature sensor 560A to determine a temperature profile of the first area and the second area of the print zone.

[0063] As mentioned above where it is determined that a thermal gradient exists between at least two different areas of the print zone, at least one energy emitter may be controlled, by the controller (not shown), to modify its irradiation power so that substantially all locations of the surface of the print zone are heated to substantially the same temperature.

[0064] The controller may determine the parameter of the energy source based on the difference between the power consumption of the first energy emitter 525A and the power consumption of the second energy emitter 545A. In an example, the controller may determine the parameter based on the difference between the cycle times of a Pulse-Width Modulation (PWM) related to the power consumption of the first energy emitter 525A and the PWM related to the power consumption of the second energy emitter 545A. A PWM signal is a digital signal in which the cycle time of the “on” and the “off” states is changed to modify the power applied to a device. The controller may determine the parameter of the energy source by comparing the “on” time of the PWM signal of the first and second energy emitters 525A-545A. Based on the parameter determination, the controller is to set at least one of the first air flow rate, and the second air flow rate to be used during the processing of subsequent 3D printing operations.

[0065] Fig. 5B is a block diagram illustrating another example of an energy source 500B. The energy source 500B may be the same energy source or a similar energy source as the energy source 140 from Fig. 1. Alternatively, the energy source 500A may be a similar energy source as the energy source 500A from Fig. 5A. The energy source 500B comprises an array of energy sources. The print zone may comprise a first area and a second area. The energy source array 500B may also include a temperature sensor 560B. The temperature sensor 560B may be the same as or similar to the temperature sensor 560A from Fig. 5A.

[0066] The energy emitters from the array of energy sources may be split into a plurality of subgroups, for example, a first subgroup 520B and a second subgroup 540B. In the illustrated example, the first subgroup 520B comprises a plurality of energy emitters, e.g. five energy emitters 521B-525B, and the second subgroup 540B comprises another plurality of energy emitters, e.g. five energy emitters 541B-545B. In other examples, the amount of energy

emitters in the first subgroup 520B may a different amount of emitters than the amount of energy emitters in the second subgroup 540B. The first plurality of energy emitters 521B-525B may be to apply energy to the build material in the first area of the print zone (not shown). The first area of the print zone may be the same area or a similar area as the first area 182 shown in Fig. 1. Likewise, the second energy emitter 545A is to apply energy to the build material in the second area of the print zone (not shown). The second area of the print zone may be the same area or a similar area as the second area 184 from Fig. 1.

[0067] The energy source 500B may be coupled to a controller (not shown). In an example, the controller may also be coupled to the temperature sensor 560B. The controller may be to perform at least the same operations as the controller 160 from Fig. 1. The controller may control the temperature sensor 560B to determine a temperature profile of the first area and the second area of the print zone.

[0068] The controller may modify, based on the temperature profile, the amount of energy applied by the first plurality of energy emitters 521A-525B and the second plurality of energy emitters 541B-545B, to cause a substantially uniform heating of the build material layer. The controller may further determine the parameter of the energy source, based on the difference between the power consumption of the first plurality of energy emitters 521B-525B and the power consumption of the second plurality of energy emitters 541B-545B. In an example, the controller may determine the parameter based on the difference between the total power consumption of the first plurality of energy emitters 521B-525B and the total power consumption of the second plurality of energy emitters 541B-545B. In another example, the controller may determine the parameter based on the difference between the average power consumption of the first plurality of energy emitters 521B-525B and the average power consumption of the second plurality of energy emitters 541B-545B. Based on the parameter determination, the controller is to set at least one of the first air flow rate, and the second air flow rate to be used during the processing of subsequent 3D printing operations.

[0069] Fig. 6 is a block diagram illustrating another example of an additive manufacturing system 600 to set air flow rates for 3D printing. The additive manufacturing system 600

comprises a cooling module 620, an energy source 640, a layering module 650 and a printing module 690. The cooling module 620 and the energy source 640 may be the same as or similar to the cooling module 120 and the energy source 140 from Fig. 1. The layering module 650 may be the same as or similar to the layering module 250 from Fig. 2.

[0070] The layering module 650 may be to supply a print zone, e.g. print zone 180 shown in Fig. 1, with a layer of build material. The printing module 690 may be any apparatus, mechanism, and/or group of elements to selectively print a pattern corresponding to a layer of a 3D object to be built on each build material layer. An example of printing module 690 may be a printhead to selectively print a pattern of fusing agent on each build material layer corresponding to the portions of the layer to be fused. In this example, the energy source 640 may apply energy to the layer to selectively solidify portions of the build material layer on which fusing agent was printed.

[0071] The additive manufacturing system 600 also comprises a controller 660. The controller 660 may be to perform at least the same operations as the controller 160 shown Fig. 1 or any other controller disclosed herein. The controller 600 may set at least one of the first flow rate and the second flow rate to be used during the processing of subsequent 3D printing operations based on the determined parameter of the energy source and/or the characteristic of the first air flow and the second air flow. Additionally, in some examples, the controller 600 may determine the first flow rate and the second flow rate to be used in subsequent 3D printing operations by also controlling the layering module 650 to supply a set of pluralities of build material layers 680A-680D (see, e.g., Fig. 2). The plurality of sets of build material layers 680A-680D may be the same as the plurality of sets of build material layers 280A-280D.

[0072] The controller 660 may control the layering module 650 to supply a first additional set of build material layers 680E. In some examples, the first additional set of build material layers 680E may be supplied on top of the set of build material layers 680A-680D. In other examples, the first additional set of build material layers 680E may be supplied as the plurality of build material layers to be generated on the build platform. In additional examples, the width of the

set of build material layers 680E may be substantially the same as the width of any of the set of build material layers 680A-680D.

[0073] The controller 660 may further control the printing module 690 to print patterns of fusing agent that will form a first calibration object on some of the layers of the first additional set of build material layers 680E. In some examples, the controller 660 may instruct the cooling module 620 to cause the calibrated airflow rates, i.e. first air flow rate and the second air flow rate, during the printing of the patterns to form the first calibration object. Additionally, or alternatively, the controller 660 may instruct the energy source 640 to set the energy source array in a first configuration during the printing of the patterns to form the first calibration object. Examples of a calibration object, e.g. first calibration object, are shown in more detail in Fig. 7A and 7B.

[0074] In an additional example, the controller 660 may control the printing module 690 to print patterns of fusing agent that will form a plurality of first calibration objects distributed over the build bed. In an example, the each of the first calibration objects may comprise substantially the same geometry. The conditions in which the plurality of first calibration objects are generated may be the same as or similar to the conditions described above with respect to the generation of the first calibration object.

[0075] The energy source configuration may be understood as the configuration of the energy emitters within the energy source array, see, e.g., Fig. 5A and 5B. In an example, the energy source configuration comprises which energy emitters are emitting energy and which energy emitters are not emitting energy during the generation of the 3D calibration object. In another example, the energy configuration comprises the power intensity at which the plurality of emitters within the energy source array may be set during the generation of the 3D calibration object.

[0076] Once the first calibration object is generated, the controller 660 may (i) instruct the layering module 650 to supply additional build material layers, or (ii) determine that the print job has finished.

[0077] In an example, the controller 660 determines that the print job has finished, the controller 660 may obtain a first measurement from the formed first calibration object. In some examples, the measurement is a physical measurement, for example, the length of a portion of the first calibration object, e.g. dog-bone neck. In other examples, the measurement is an aesthetic measurement, for example, the color of a part of the first calibration object. In yet another example, the measurement is a property of the first calibration object, for example, strength, resilience, and the like. The previous measurements may be measured and inputted to the controller 660 by a user.

[0078] In another example, the controller 660 may further instruct the layering module 650 to supply a second additional set of build material layers 680F. The controller 660 may also control the printing module 690 to print patterns of fusing agent that will form a second calibration object on some of the layers of the second additional set of build material layers. In an example, the second calibration object may comprise substantially the same geometry as the first calibration object. The controller 660 may further instruct the cooling module 620 to cause the calibrated airflow rates, i.e. first air flow rate and the second air flow rate, during the printing of the patterns to form the second calibration object. Additionally, or alternatively, the controller 660 may instruct the energy source 640 to set the energy source array in a second configuration during the printing of the patterns to form the first calibration object. In an example, the second configuration of the energy source 640 may be a different configuration than the first configuration of the energy source array 640. Once the second calibration object is generated, the controller may obtain a second measurement from the formed second calibration object. In an example, the second measurement from the second calibration object may measure the same variable and/or parameter than the first measurement from the first calibration object.

[0079] In an additional example, the controller 660 may control the printing module 690 to print fusing agent patterns that will form a plurality of second calibration objects distributed over the build bed. In an example, the plurality of second calibration objects may have substantially the same geometry as each other. Additionally, or alternatively, the geometry of each of the plurality of second calibration objects may be substantially the same as the

geometry of the first calibration object. The conditions in which the plurality of second calibration objects are generated may be the same as or similar to the conditions described above with respect to the generation of the second calibration object.

[0080] In an example of the present disclosure the first calibration object and the second calibration object are generated based on an object model, e.g., CAD object model. The controller 660 may compare the first measurement and the second measurement with the corresponding dimensions of the object model. For example, if the measurement is the length of the side A of the calibration object, the controller 660 may compare (i) the length of the side A of the first calibration object with the length of the side A of the object model, and (ii) the length of the side A of the second calibration object with the length of the side A of the object model. Based on the previous comparisons, the controller 660 may determine which of the first calibration measurement or the second calibration measurement more closely corresponds to the equivalent dimension of the object model.

[0081] If, for example, the controller 660 determines that the first measurement is the measurement that more closely corresponds to the equivalent dimension of the object model, the controller 660 may set, i.e. calibrate, the energy source 640 array used during the processing of subsequent 3D printing operations in the first energy source 640 configuration. Similarly, if the controller 660 determines that the second measurement is the measurement that more closely corresponds to the equivalent dimension of the object model, the controller 660 may set, i.e. calibrate, the energy source 640 array used during the processing of subsequent 3D printing operations in the second energy source 640 configuration.

[0082] In a different example, the controller 660 may receive measurement data from each calibration object from the plurality of first calibration objects and measurement data from each calibration object from the plurality of second calibration objects. The received measurements may measure the same parameter. In an example, the plurality of first calibration objects and the plurality of second calibration objects may be measured by the user. In another example, the plurality of first calibration objects and the plurality of second calibration objects may be measured automatically by a 3D scanner, or any other similar

automatic device, coupled to the controller 660. The controller may receive the measurements through an input from the user or from the 3D scanner, or similar device.

[0083] Following with the example, the controller 660 may determine (i) a first deviation parameter among the plurality of first calibration object measurements, and (ii) a second deviation parameter among the plurality of second calibration object measurements. In an example, the deviation parameter may be the standard deviation. In other examples, the deviation parameter may be any parameter that indicates how disperse are the plurality of measurements, i.e. how far from the average.

[0084] If, for example, the controller 660 determines that the first deviation parameter is narrower than the second deviation parameter, the controller 660 is further to set, i.e. calibrate, the energy source 640 array to be used during the processing of subsequent 3D printing operations in the first energy source array configuration. Similarly, if the controller 660 determines that the second deviation parameter is narrower than the first deviation parameter, the controller 660 is further to set, i.e. calibrate, the energy source array used during the processing of subsequent 3D printing operations in the second energy source array configuration.

[0085] Fig. 7A is a schematic diagram illustrating an example of a calibration object 700A. The calibration object 700A is a dog-bone neck.

[0086] Fig. 7B is a schematic diagram illustrating another example of a calibration object 700B. The calibration object 700B is a disk comprising a circle 820 with a predetermined thickness.

[0087] Fig. 8 is a flowchart of an example method 800 for setting air flow rates for 3D printing. Method 800 may be described below as being executed or performed by an additive manufacturing system, such as additive manufacturing system 100 of FIG. 1. Various other suitable systems may be used as well, such as, for example system 200 of FIG. 2, system 400 from Fig. 4, and system 600 from Fig. 6. Method 800 may be implemented in the form of executable instructions stored on a machine-readable storage medium and executed by a single processor or a plurality of processors of the apparatus 100, and/or in the form of any electronic circuitry, for example digital and/or analog ASIC. In some implementations of the present

disclosure, method 800 may include more or less blocks than are shown in FIG. 8. In some implementations, at least one of the blocks of method 800 may, at certain times, be performed in parallel and/or may repeat.

[0088] Method 800 may start at block 810, and continue to block 820, where at least one fan causes a first dominant air flow and a second dominant air flow to have a first predetermined flow rate and a second predetermined flow rate respectively, wherein the first air flow and the second air flow are caused over a build bed. At block 830, an energy source may apply energy to the build bed. At block 840 a sensor may measure a temperature of the first air flow and the second air flow. At block 850, a controller, may determine a temperature gradient between the first air flow and the second air flow. At block 860, a cooling adjusting mechanism, may adjust the first air flow rate and the second air flow rate to be used during the processing of subsequent 3D printing operations based on the temperature gradient. At block 870, method 800 may end.

[0089] Fig. 9 is a flowchart of another example method for setting air flow rates for 3D printing. In some examples, method 900 may be executed after block 860 from method 800. Method 900 may be described below as being executed or performed by an additive manufacturing system, such as additive manufacturing system 100 of FIG. 1. Various other suitable systems may be used as well, such as, for example system 200 of FIG. 2, system 400 from Fig. 4, and system 600 from Fig. 6. Method 900 may be implemented in the form of executable instructions stored on a machine-readable storage medium and executed by a single processor or a plurality of processors of the apparatus 100, and/or in the form of any electronic circuitry, for example digital and/or analog ASIC. In some implementations of the present disclosure, method 900 may include more or less blocks than are shown in FIG. 9. In some implementations, at least one of the blocks of method 800 may, at certain times, be performed in parallel and/or may repeat.

[0090] Method 900 may start at block 910 where a layering module may supply a plurality of build material layers to the build platform. At block 920, an additive manufacturing system may generate a 3D calibration object using at least some of the plurality of build material layers,

wherein the printing is performed under (i) the first air flow and the second air flow conditions, and (ii) a preset energy configuration of an energy source array. At block 930, a controller may obtain a measurement from the 3D calibration object. At block 940, the controller may determine whether the measurement is an acceptable measurement by comparing the measurement with the equivalent intended dimension. At block 950, the controller may set the energy source array in the preset energy configuration during the processing of subsequent 3D printing operations, where it is determined that the measurement is an acceptable measurement. At block 960, the controller may set the energy source array in a different energy configuration than the preset energy configuration during the processing of subsequent 3D print operations, where it is determined that the measurement is an unacceptable measurement.

[0091] Fig. 10 is a block diagram illustrating an example of a processor-based system 1000 to set air flow rates for 3D printing. In some implementations, the system 1000 may be or may form part of an additive manufacturing system (e.g., additive manufacturing system 100 from Fig. 1). In some implementations, the system 1000 is a processor-based system and may include a processor 1010 coupled to a machine-readable medium 1020. The processor 1010 may include a single-core processor, a multi-core processor, an application-specific integrated circuit (ASIC), a field programmable gate array (FPGA), and/or any other hardware device suitable for retrieval and/or execution of instructions from the machine-readable medium 1020 (e.g., instructions 1021-1025) to perform functions related to various examples. Additionally, or alternatively, the processor 1010 may include electronic circuitry for performing the functionality described herein, including the functionality of instructions 1021-1025. With respect of the executable instructions represented as boxes in FIG. 10, it should be understood that part or all of the executable instructions and/or electronic circuits included within one box may, in alternative implementations, be included in a different box shown in the figures or in a different box not shown.

[0092] The machine-readable medium 1020 may be any medium suitable for storing executable instructions, such as a random-access memory (RAM), electrically erasable programmable read-only memory (EEPROM), flash memory, hard disk drives, optical disks, and

the like. In some example implementations, the machine-readable medium 1020 may be a tangible, non-transitory medium, where the term “non-transitory” does not encompass transitory propagating signals. The machine-readable medium 1020 may be disposed within the processor-based system 1000, as shown in FIG. 10, in which case the executable instructions may be deemed “installed” on the system 1000. Alternatively, the machine-readable medium 1020 may be a portable (e.g., external) storage medium, for example, that allows system 1000 to remotely execute the instructions or download the instructions from the storage medium. In this case, the executable instructions may be part of an “installation package”. As described further herein below, the machine-readable medium may be encoded with a set of executable instructions 1021-1025.

[0093] Instructions 1021, when executed by the processor 1010, may cause the processor 1010 to cause a first dominant air flow having a first air flow rate over a first area of a build bed and a second dominant air flow having a second air flow rate over a second area of the build bed. Instructions 1022, when executed by the processor 1010, may cause the processor 1010 to determine a temperature profile of the first area and the second area. Instructions 1023, when executed by the processor 1010, may cause the processor 1010 to modify, based on the temperature profile, the amount of energy applied to a first energy emitter and a second energy emitter to cause a substantially uniform heating of a layer of build material on the build bed. Instructions 1024, when executed by the processor 1010, may cause the processor 1010 to adjust the first air flow rate and the second air flow rate based on a difference between a power consumption of the first energy emitter and a power consumption of the second energy emitter. Instructions 1025, when executed by the processor 1010, may cause the processor 1010 to set at least one of the first air flow to the first adjusted air flow rate and the second air flow to the second adjusted air flow rate during the processing of subsequent 3D printing operations.

[0094] In an example the machine-readable medium 1020 may be encoded with an additional set of executable instructions. For example, the machine-readable medium 1020 may comprise instructions that, when executed by the processor 1010, may cause the processor 1010 to supply a plurality of build material layers to the build platform. For example, the machine-

readable medium 1020 may comprise instructions that, when executed by the processor 1010, may cause the processor 1010 to generate a 3D calibration object using at least some of the plurality of build material layers, wherein the printing is to be performed under (i) the first air flow rate and the second air flow rate conditions, and (ii) an energy configuration of an energy source array. For example, the machine-readable medium 1020 may comprise instructions that, when executed by the processor 1010, may cause the processor 1010 to obtain a measurement from the 3D calibration object. For example, the machine-readable medium 1020 may comprise instructions that, when executed by the processor 1010, may cause the processor 1010 to determine whether the measurement is an acceptable measurement by comparing the measurement with the equivalent intended dimension. For example, the machine-readable medium 1020 may comprise instructions that, when executed by the processor 1010, may cause the processor 1010 to set the energy source array in the preset energy configuration during the processing of subsequent 3D printing operations, where it is determined that the measurement is an acceptable measurement. For example, the machine-readable medium 1020 may comprise instructions that, when executed by the processor 1010, may cause the processor 1010 to set the energy source array in a different energy configuration than the preset energy configuration during the processing of subsequent 3D printing operations, where it is determined that the measurement is an unacceptable measurement.

[0095] The above examples may be implemented by hardware, or software in combination with hardware. For example, the various methods, processes and functional modules described herein may be implemented by a physical processor (the term processor is to be implemented broadly to include CPU, SoC, processing module, ASIC, logic module, or programmable gate array, etc.). The processes, methods and functional modules may all be performed by a single processor or split between several processors; reference in this disclosure or the claims to a “processor” should thus be interpreted to mean “at least one processor”. The processes, method and functional modules are implemented as machine-readable instructions executable by at least one processor, hardware logic circuitry of the at least one processors, or a combination thereof.

[0096] The drawings in the examples of the present disclosure are some examples. It should be noted that some units and functions of the procedure may be combined into one unit or further divided into multiple sub-units. What has been described and illustrated herein is an example of the disclosure along with some of its variations. The terms, descriptions and figures used herein are set forth by way of illustration. Many variations are possible within the scope of the disclosure, which is intended to be defined by the following claims and their equivalents.

[0097] Example implementations can be realized according to the following clauses:

[0098] Clause 1: An additive manufacturing system comprising (i) a cooling module to cause a first dominant air flow over a first area of a print zone and a second dominant air flow over a second area of the print zone, (ii) an energy source to apply energy to the print zone; and (iii) a controller to: (a) determine air flow calibration characteristics by: controlling the cooling module to cause the first air flow to have a first predetermined flow rate and the second air flow to have a second predetermined flow rate, controlling the energy source to apply energy to the print zone, determining at least one of a parameter of the energy source, and a characteristic of the first air flow and the second air flow; and (b) set at least one of the first air flow rate, and the second air flow rate to be used during the processing of subsequent 3D printing operations based on the determined parameter or characteristic.

[0099] Clause 2: The additive manufacturing system of clause 1, wherein the controller is further to: obtain a temperature of the first air flow and the second air flow; and determine the characteristic based on a difference of temperature between the first air flow and the second air flow.

[0100] Clause 3: The additive manufacturing system of any preceding clause, further comprising a layering module to supply the print zone with a build material layer, the controller further to control the layering module to supply a set of pluralities of build material layers.

[0101] Clause 4: The additive manufacturing system of any preceding clause, wherein for each of the pluralities of build material layers, the controller is to: control the cooling module to modify the air flow rate of at least one of the first air flow and the second air flow; and

determine at least one of the parameter of the energy source, and the characteristic of the first air flow and the second air flow.

[0102] Clause 5: The additive manufacturing system of any preceding clause, wherein the cooling module comprises: (i) a first cooling mechanism to cause the first air flow over the first area; (ii) a second cooling mechanism to cause the second air flow over the second area; and (iii) a cooling adjusting mechanism to adjust the first flow rate of the first air flow and the second flow rate of the second air flow; wherein the controller is further to adjust at least one of the first flow rate and the second flow rate based on at least one of the determined parameter and characteristic.

[0103] Clause 6: The additive manufacturing system of any preceding clause, further comprising: the energy source further comprising an array of energy sources including a first energy emitter to apply energy predominantly to the first area of the print zone and a second energy emitter to apply energy predominantly to the second area of the print zone; and the controller further to: (i) determine a temperature profile of the first area and the second area, (ii) modify, based on the temperature profile, the amount of energy applied by the first energy emitter and the second energy emitter to cause a substantially uniform heating of the layer, and (iii) determine the parameter based on the difference between the power consumption of the first energy emitter and the power consumption of the second energy emitter.

[0104] Clause 7: The additive manufacturing system of any preceding clause, further comprising: a layering module to supply a print zone with a layer of build material; a printing module to selectively print a pattern of fusing agent on each build material layer; the energy source to apply energy to the layer to selectively solidify portions of the layer on which fusing agent was printed; and the controller to: (i) control the layering module to supply a first additional plurality of build material layers; (ii) control the printing module to print patterns that will form a first calibration object on at least some of the layers of the first additional plurality of build material layers, whilst (a) the cooling module is causing the first air flow rate and the second air flow rate, and (b) the energy source array is set in a first configuration; and (iii) obtain a first measurement from the formed first calibration object.

[0105] Clause 8: The additive manufacturing system of any preceding clause, wherein the first calibration object comprises at least one of a dog-bone neck and a disk.

[0106] Clause 9: The additive manufacturing system of any preceding clause, wherein the controller is to: (i) control the layering module to supply a second additional plurality of build material layers to the build bed; (ii) control the printing module to print patterns that will form a second calibration object on at least some of the layers of the second additional plurality of build material layers, whilst (a) the cooling module is causing the first air flow rate and the second air flow rate, and (b) the energy source array is set in a second configuration; and (iii) obtain at least a second measurement from the formed second calibration object.

[0107] Clause 10: The additive manufacturing system of any preceding clause, wherein the first calibration object and the second calibration object are associated with an object model, the controller is further to: (i) compare the first measurement and the second measurement with the corresponding dimensions of the object model; (ii) determine which of the measurements more closely corresponds to the equivalent dimension of the object model; (iii) set the energy source array used during the processing of subsequent 3D printing operations in the first energy source array configuration, where it is determined that the first measurement is the measurement that more closely corresponds to the equivalent dimension of the object model; and (iv) set the energy source array used during the processing of subsequent 3D printing operations in the second energy source array configuration, where it is determined that the second measurement is the measurement that more closely corresponds to the equivalent dimension of the object model.

[0108] Clause 11: The additive manufacturing system of any preceding clause, the controller further to: (i) control the printing module to print a plurality of first calibration objects across the print zone whilst the energy source is set in the first configuration; (ii) control the printing module to print a plurality of second calibration objects across the print zone whilst the energy source is set in the second configuration; (iii) receive a plurality of first calibration object measurements corresponding to the plurality of first calibration objects and a plurality of second calibration object measurements corresponding to the plurality of second calibration

objects; (iv) determine a first deviation parameter among the plurality of first calibration object measurements; (v) determine a second deviation parameter among the plurality of second calibration object measurements; (vi) set the energy source array used during the processing of subsequent 3D printing operations in the first energy source array configuration, where it is determined that the first deviation parameter is narrower than the second deviation parameter; and (vii) set the energy source array used during the processing of subsequent 3D printing operations in the second energy source array configuration, where it is determined that the second deviation parameter is narrower than the first deviation parameter.

[0109] Clause 12: A method comprising (i) causing, by at least one fan, a first dominant air flow and a second dominant air flow to have a first predetermined flow rate and a second predetermined flow rate respectively, wherein the first air flow and the second air flow are caused over a build bed; (ii) applying energy to the build bed; (iii) measuring a temperature of the first air flow and the second air flow; (iv) determining a temperature gradient between the first air flow and the second air flow; and (v) adjusting the first air flow rate and the second air flow rate to be used during the processing of subsequent 3D printing operations based on the temperature gradient.

[0110] Clause 13: The method of clause 12, further comprising: (i) supplying a plurality of build material layers to the build bed; (ii) generating a 3D calibration object using at least some of the plurality of build material layers, wherein the printing is performed under (a) the first air flow and the second air flow conditions and (b) a preset energy configuration of an energy source array; (iii) obtaining a measurement from the 3D calibration object; (iv) determining whether the measurement is an acceptable measurement by comparing the measurement with the equivalent intended dimension; (v) setting the energy source array in the preset energy configuration during the processing of subsequent 3D printing operations, where it is determined that the measurement is an acceptable measurement; and (vi) setting the energy source array in a different energy configuration than the preset energy configuration during the processing of subsequent 3D print operations, where it is determined that the measurement is an unacceptable measurement.

[0111] Clause 14: A non-transitory machine-readable medium storing instructions executable by a processor, the non-transitory machine-readable medium comprising (i) instructions to cause a first dominant air flow having a first air flow rate over a first area of a build bed and a second dominant air flow having a second air flow rate over a second area of the build bed; (ii) instructions to determine a temperature profile of the first area and the second area; (iii) instructions to modify, based on the temperature profile, the amount of energy applied to a first energy emitter and a second energy emitter to cause a substantially uniform heating of a layer of build material on the build bed; (iv) instructions to adjust the first air flow rate and the second air flow rate based on a difference between a power consumption of the first energy emitter and a power consumption of the second energy emitter; and (v) instructions to set at least one of the first air flow to the first adjusted air flow rate and the second air flow to the second adjusted air flow rate during the processing of subsequent 3D printing operations.

[0112] Clause 15: The non-transitory machine-readable medium of clause 14, further comprising: (i) instructions to supply a plurality of build material layers to the build bed; (ii) instructions to generate a 3D calibration object using at least some of the plurality of build material layers, wherein the printing is to be performed under (a) the first air flow rate and the second air flow rate conditions, and (b) an energy configuration of an energy source array; (iii) instructions to obtain a measurement from the 3D calibration object; (iv) instructions to determine whether the measurement is an acceptable measurement by comparing the measurement with the equivalent intended dimension; (v) instructions to set the energy source array in the preset energy configuration during the processing of subsequent 3D printing operations, where it is determined that the measurement is an acceptable measurement; and (vi) instructions to set the energy source array in a different energy configuration than the preset energy configuration during the processing of subsequent 3D printing operations, where it is determined that the measurement is an unacceptable measurement.

CLAIMS

WHAT IT IS CLAIMED IS:

1. An additive manufacturing system comprising:
 - a cooling module to cause a first dominant air flow over a first area of a print zone and a second dominant air flow over a second area of the print zone;
 - an energy source to apply energy to the print zone; and
 - a controller to:
 - (i) determine air flow calibration characteristics by:
 - controlling the cooling module to cause the first air flow to have a first predetermined flow rate and the second air flow to have a second predetermined flow rate,
 - controlling the energy source to apply energy to the print zone,
 - determining at least one of a parameter of the energy source, and
 - a characteristic of the first air flow and the second air flow; and
 - (ii) set at least one of the first air flow rate, and the second air flow rate to be used during the processing of subsequent 3D printing operations based on the determined parameter or characteristic.
2. The additive manufacturing system of claim 1, wherein the controller is further to:
 - obtain a temperature of the first air flow and the second air flow; and
 - determine the characteristic based on a difference of temperature between the first air flow and the second air flow.
3. The additive manufacturing system of claim 1, further comprising a layering module to supply the print zone with a build material layer, the controller further to control the layering module to supply a set of pluralities of build material layers.

4. The additive manufacturing system of claim 3, wherein for each of the pluralities of build material layers, the controller is to:

control the cooling module to modify the air flow rate of at least one of the first air flow and the second air flow; and

determine at least one of the parameter of the energy source, and the characteristic of the first air flow and the second air flow.

5. The additive manufacturing system of claim 1, wherein the cooling module comprises:

a first cooling mechanism to cause the first air flow over the first area;

a second cooling mechanism to cause the second air flow over the second area;

and

a cooling adjusting mechanism to adjust the first flow rate of the first air flow and the second flow rate of the second air flow;

wherein the controller is further to adjust at least one of the first flow rate and the second flow rate based on at least one of the determined parameter and characteristic.

6. The additive manufacturing system of claim 1, further comprising:

the energy source further comprising an array of energy sources including a first energy emitter to apply energy predominantly to the first area of the print zone and a second energy emitter to apply energy predominantly to the second area of the print zone; and

the controller further to:

determine a temperature profile of the first area and the second area;

modify, based on the temperature profile, the amount of energy applied by the first energy emitter and the second energy emitter to cause a substantially uniform heating of the layer, and

determine the parameter based on the difference between the power consumption of the first energy emitter and the power consumption of the second energy emitter.

7. The additive manufacturing system of claim 6, further comprising:

a layering module to supply a print zone with a layer of build material,

a printing module to selectively print a pattern of fusing agent on each build material layer;

the energy source to apply energy to the layer to selectively solidify portions of the layer on which fusing agent was printed; and

the controller to:

control the layering module to supply a first additional plurality of build material layers;

control the printing module to print patterns that will form a first calibration object on at least some of the layers of the first additional plurality of build material layers, whilst (i) the cooling module is causing the first air flow rate and the second air flow rate, and (ii) the energy source array is set in a first configuration; and

obtain a first measurement from the formed first calibration object.

8. The additive manufacturing system of claim 7, wherein the first calibration object comprises at least one of a dog-bone neck and a disk.

9. The additive manufacturing system of claim of claim 7, wherein the controller is to:

control the layering module to supply a second additional plurality of build material layers;

control the printing module to print patterns that will form a second calibration object on at least some of the layers of the second additional plurality of build material layers, whilst (i) the cooling module is causing the first air flow rate and the second air flow rate, and (ii) the energy source array is set in a second configuration; and

obtain at least a second measurement from the formed second calibration object;

10. The additive manufacturing system of claim of claim 9, wherein the first calibration object and the second calibration object are associated with an object model, the controller is further to:

compare the first measurement and the second measurement with the corresponding dimensions of the object model;

determine which of the measurements more closely corresponds to the equivalent dimension of the object model;

set the energy source array used during the processing of subsequent 3D printing operations in the first energy source array configuration, where it is determined that the first measurement is the measurement that more closely corresponds to the equivalent dimension of the object model; and

set the energy source array used during the processing of subsequent 3D printing operations in the second energy source array configuration, where it is determined that the second measurement is the measurement that more closely corresponds to the equivalent dimension of the object model.

11. The additive manufacturing system of claim 9, the controller further to:

control the printing module to print a plurality of first calibration objects across the print zone whilst the energy source is set in the first configuration;

control the printing module to print a plurality of second calibration objects across the print zone whilst the energy source is set in the second configuration;

receive a plurality of first calibration object measurements corresponding to the plurality of first calibration objects and a plurality of second calibration object measurements corresponding to the plurality of second calibration objects;

determine a first deviation parameter among the plurality of first calibration object measurements;

determine a second deviation parameter among the plurality of second calibration object measurements;

set the energy source array used during the processing of subsequent 3D printing operations in the first energy source array configuration, where it is determined that the first deviation parameter is narrower than the second deviation parameter; and

set the energy source array used during the processing of subsequent 3D printing operations in the second energy source array configuration, where it is determined that the second deviation parameter is narrower than the first deviation parameter.

12. A method comprising:

causing, by at least one fan, a first dominant air flow and a second dominant air flow to have a first predetermined flow rate and a second predetermined flow rate respectively, wherein the first air flow and the second air flow are caused over a build bed;

applying energy to the build bed;

measuring a temperature of the first air flow and the second air flow;

determining a temperature gradient between the first air flow and the second air flow; and

adjusting the first air flow rate and the second air flow rate to be used during the processing of subsequent 3D printing operations based on the temperature gradient.

13. The method of claim 12, further comprising:

supplying a plurality of build material layers to the build bed;

generating a 3D calibration object using at least some of the plurality of build material layers, wherein the printing is performed under (i) the first air flow and the second air flow conditions and (ii) a preset energy configuration of an energy source array;

obtaining a measurement from the 3D calibration object;

determining whether the measurement is an acceptable measurement by comparing the measurement with the equivalent intended dimension;

setting the energy source array in the preset energy configuration during the processing of subsequent 3D printing operations, where it is determined that the measurement is an acceptable measurement; and

setting the energy source array in a different energy configuration than the preset energy configuration during the processing of subsequent 3D print operations, where it is determined that the measurement is an unacceptable measurement.

14. A non-transitory machine-readable medium storing instructions executable by a processor, the non-transitory machine-readable medium comprising:

instructions to cause a first dominant air flow having a first air flow rate over a first area of a build bed and a second dominant air flow having a second air flow rate over a second area of the build bed;

instructions to determine a temperature profile of the first area and the second area;

instructions to modify, based on the temperature profile, the amount of energy applied to a first energy emitter and a second energy emitter to cause a substantially uniform heating of a layer of build material on the build bed;

instructions to adjust the first air flow rate and the second air flow rate based on a difference between a power consumption of the first energy emitter and a power consumption of the second energy emitter; and

instructions to set at least one of the first air flow to the first adjusted air flow rate and the second air flow to the second adjusted air flow rate during the processing of subsequent 3D printing operations.

15. The non-transitory machine-readable medium of claim 14, further comprising:

instructions to supply a plurality of build material layers to the build bed;

instructions to generate a 3D calibration object using at least some of the plurality of build material layers, wherein the printing is to be performed under (i) the first air flow rate and the second air flow rate conditions, and (ii) an energy configuration of an energy source array;

instructions to obtain a measurement from the 3D calibration object;

instructions to determine whether the measurement is an acceptable measurement by comparing the measurement with the equivalent intended dimension;

instructions to set the energy source array in the preset energy configuration during the processing of subsequent 3D printing operations, where it is determined that the measurement is an acceptable measurement; and

instructions to set the energy source array in a different energy configuration than the preset energy configuration during the processing of subsequent 3D printing operations, where it is determined that the measurement is an unacceptable measurement.

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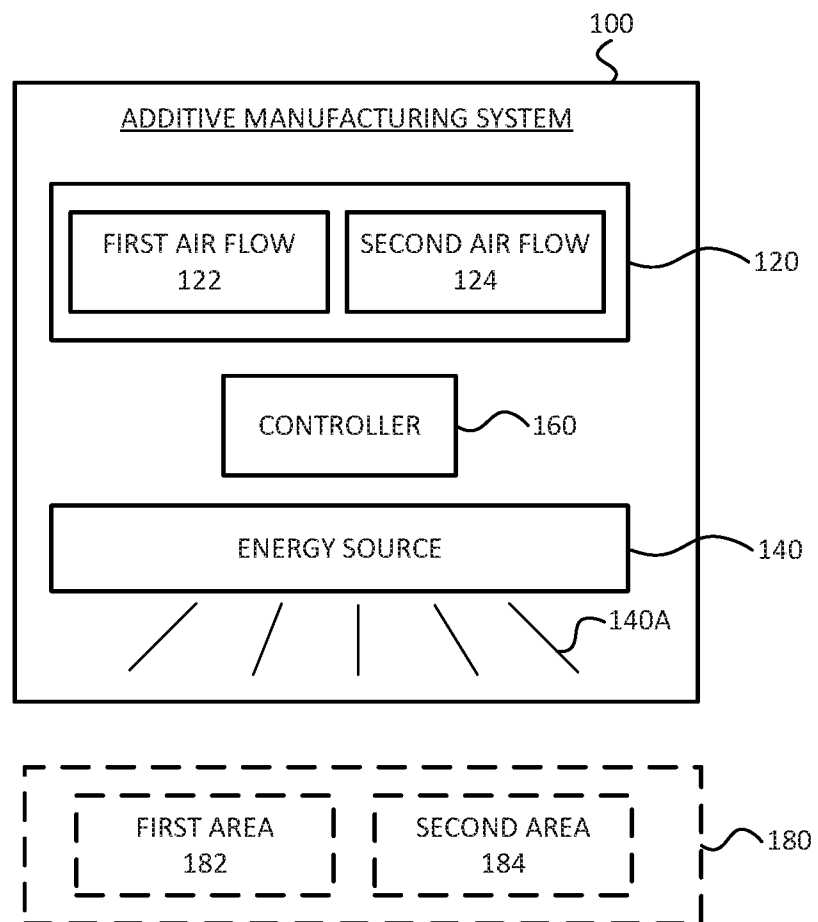


Fig. 1

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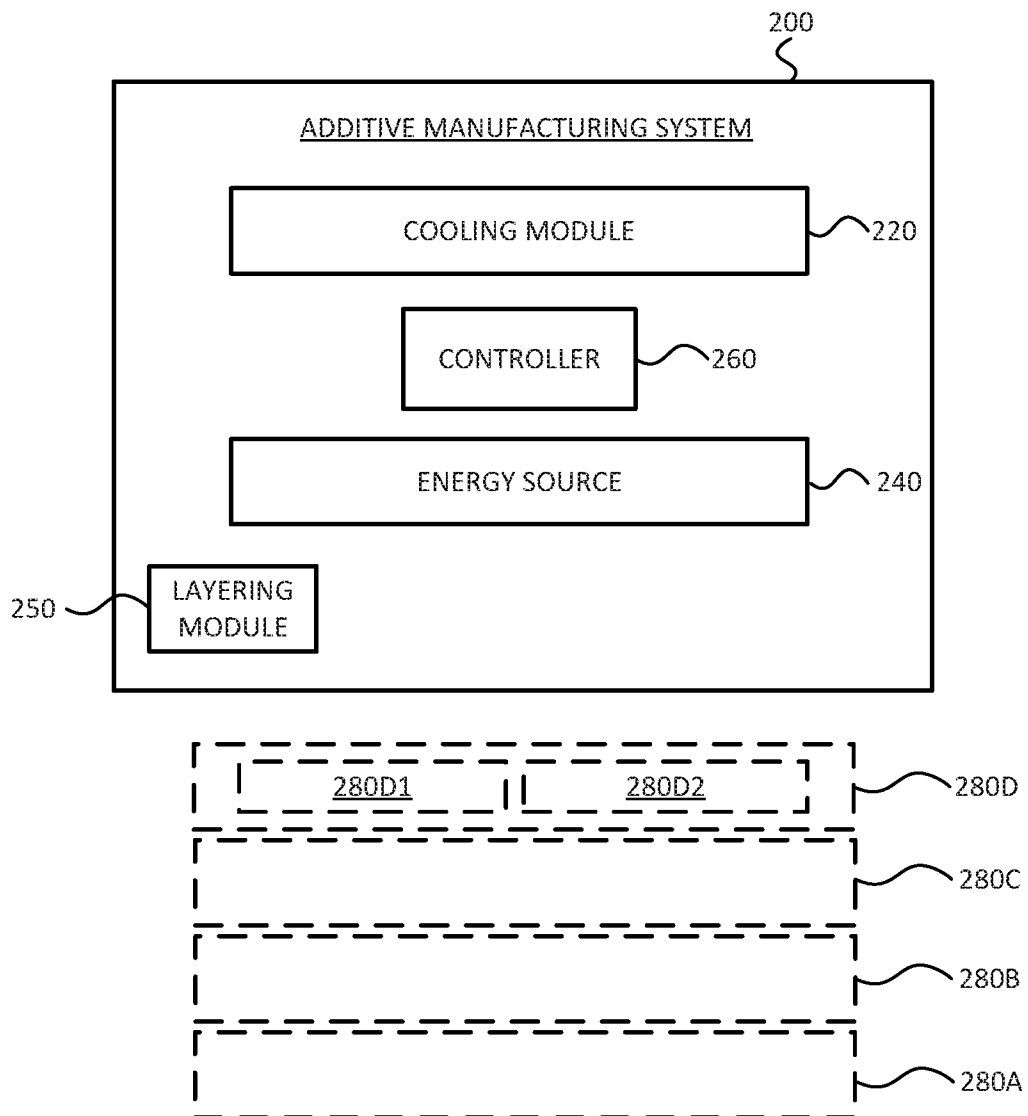


Fig. 2

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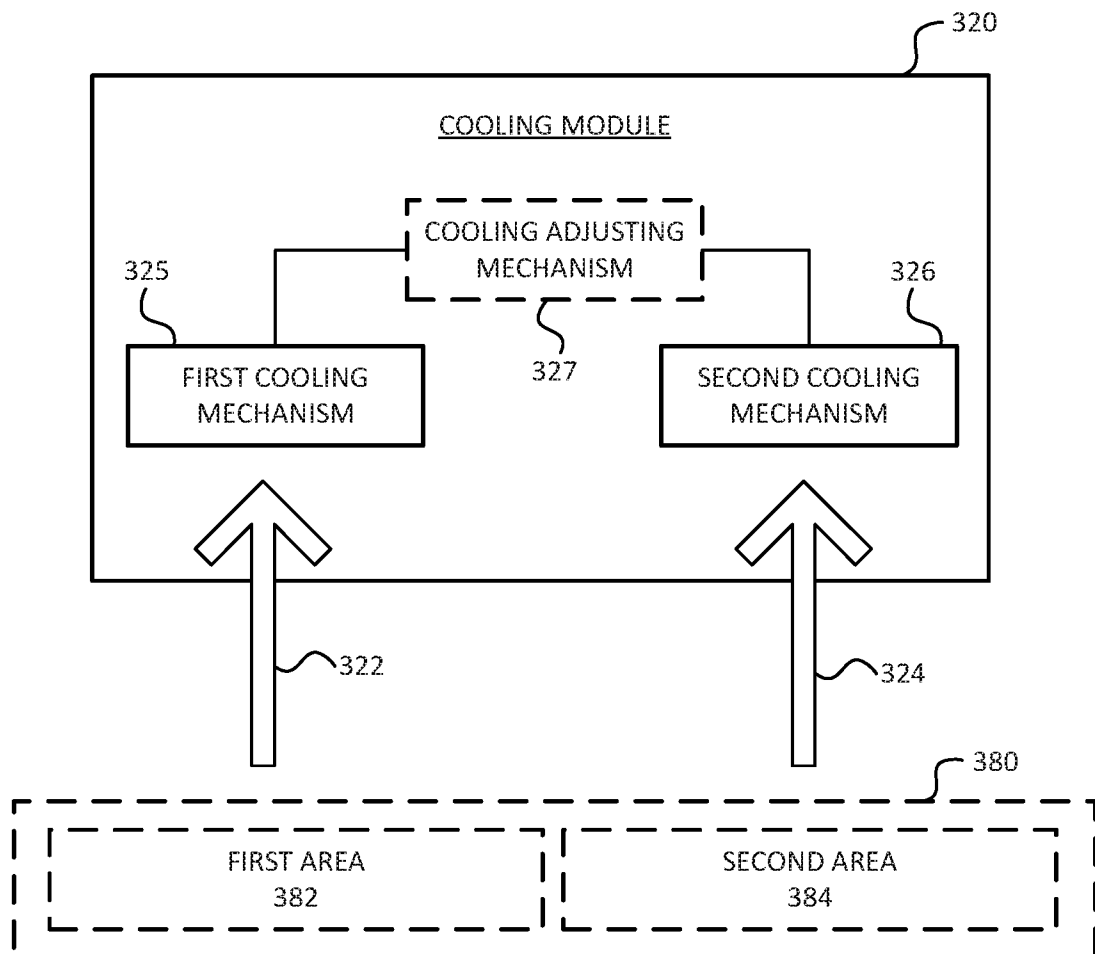


Fig. 3

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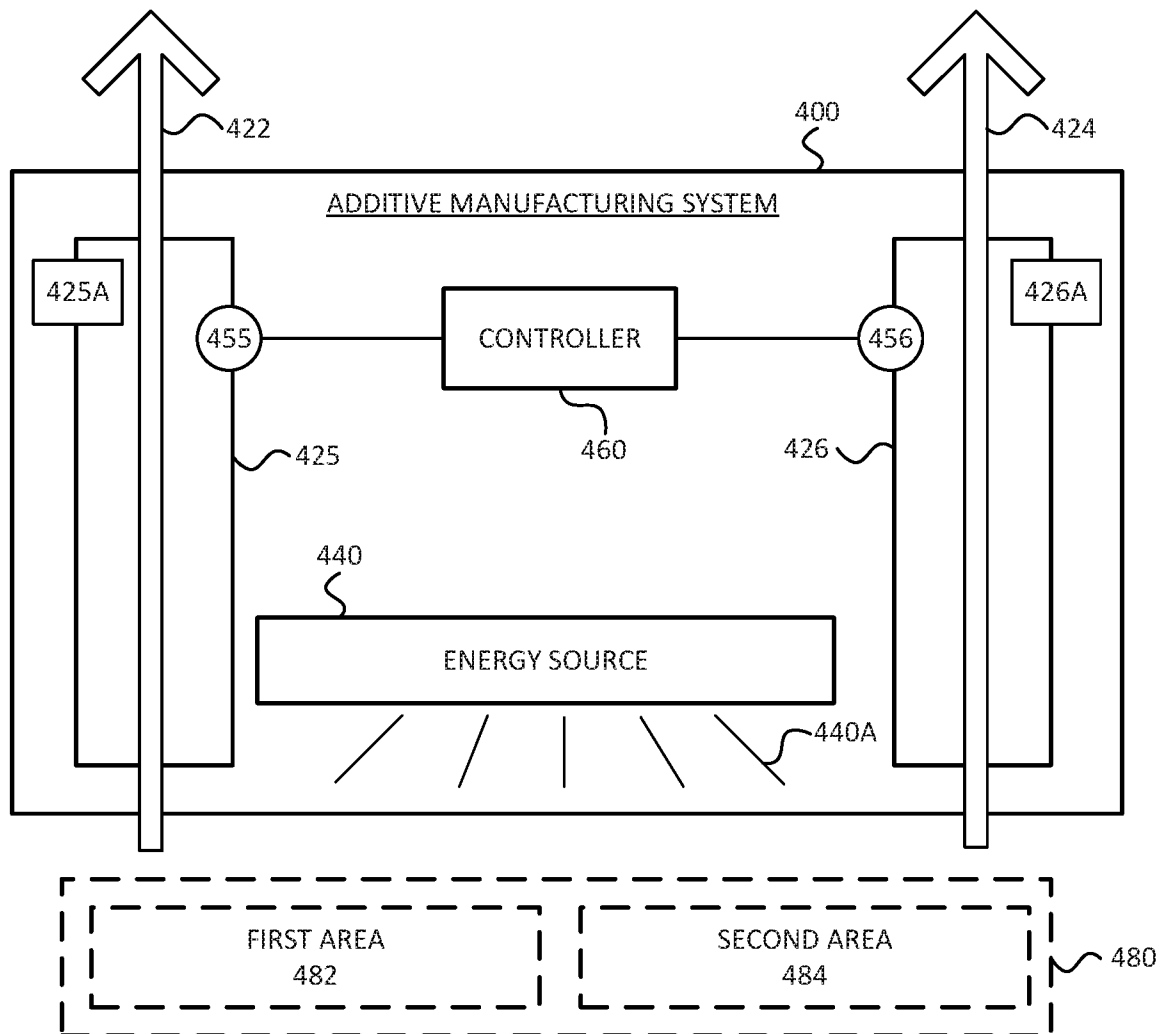


Fig. 4

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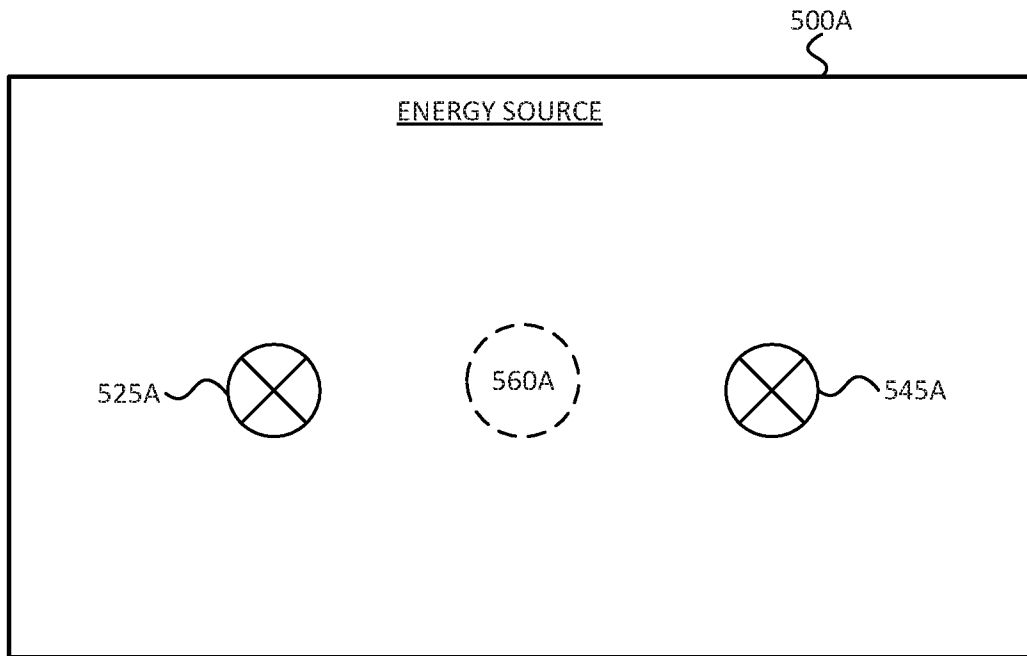


Fig. 5A

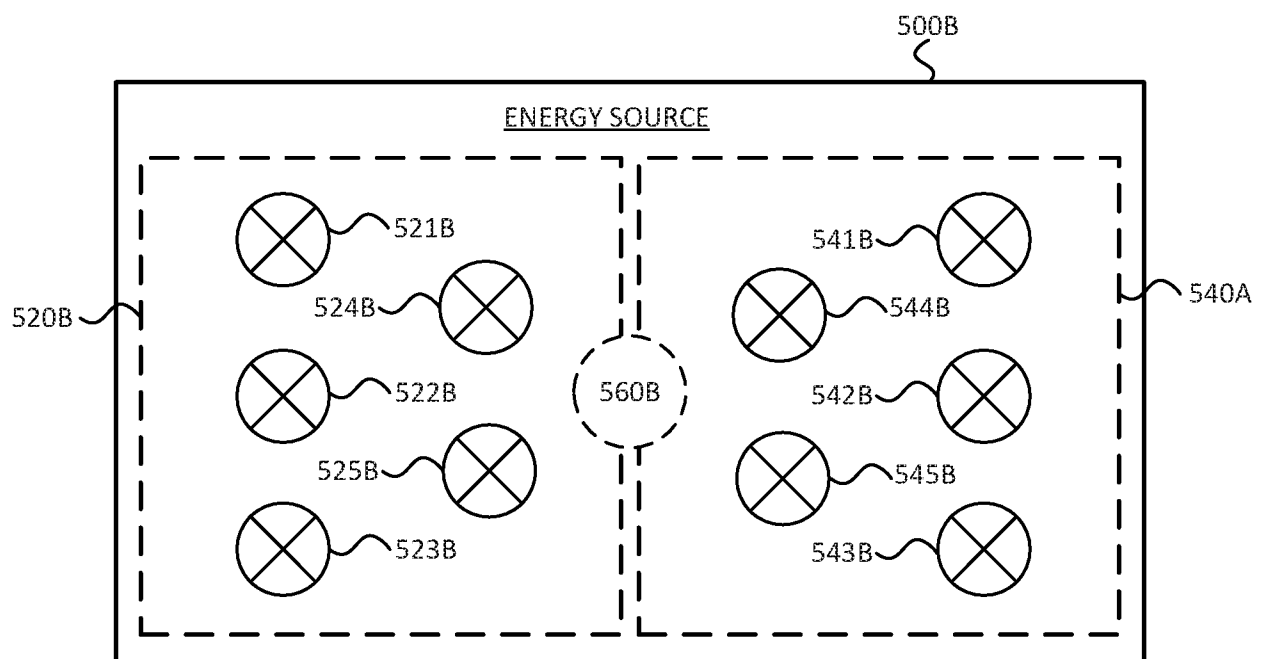


Fig. 5B

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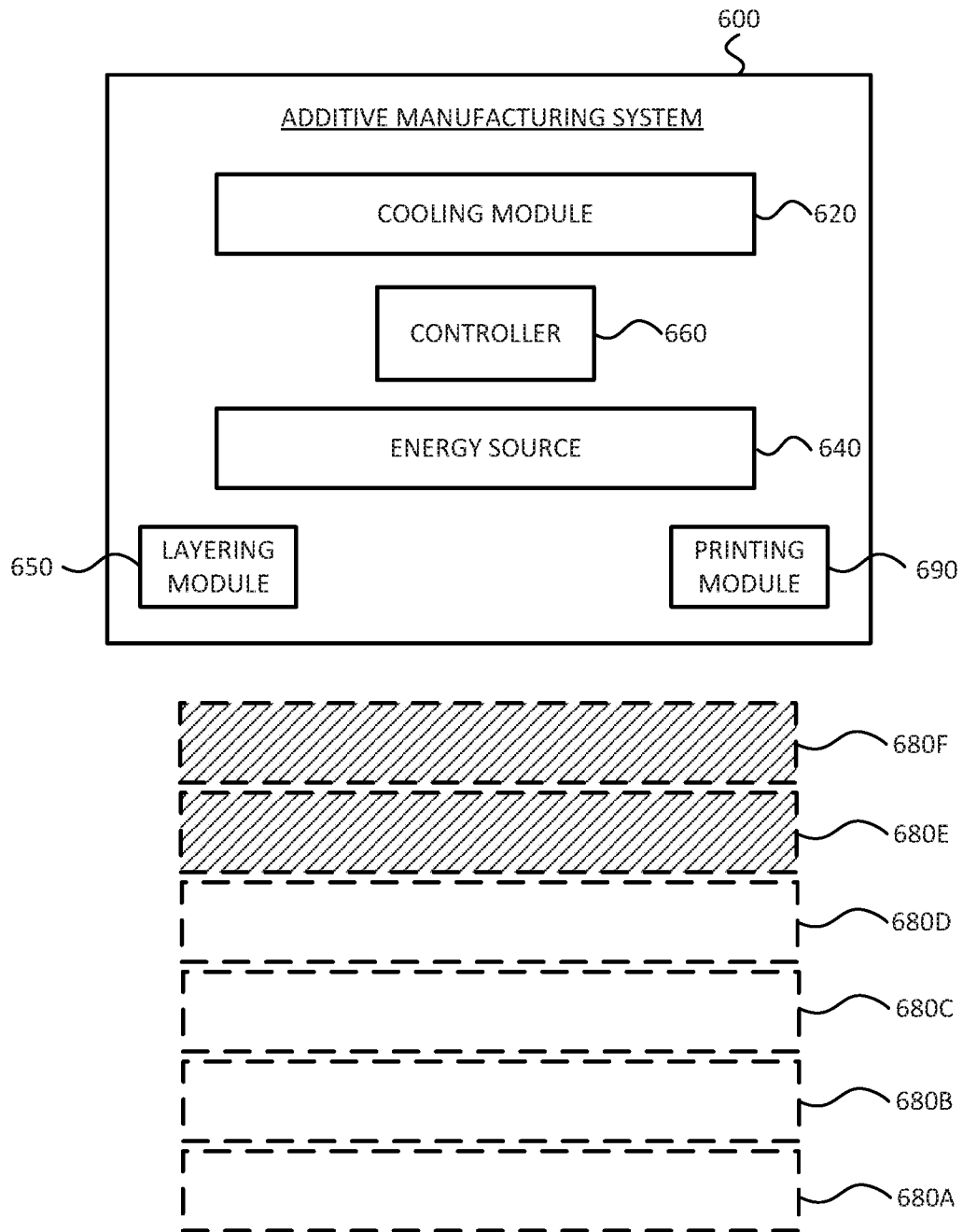


Fig. 6

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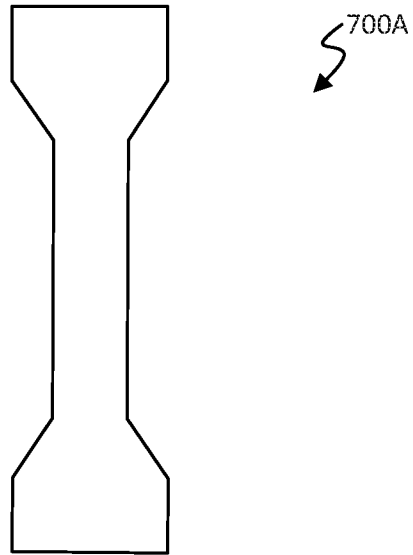


Fig. 7A

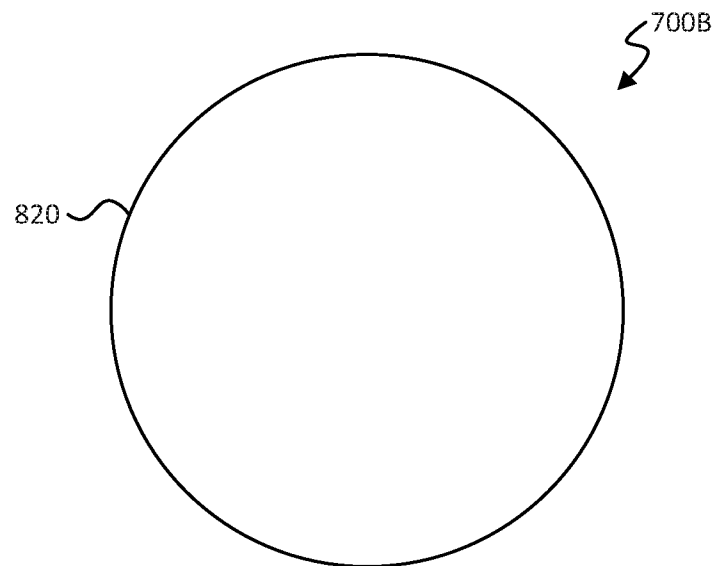


Fig. 7B

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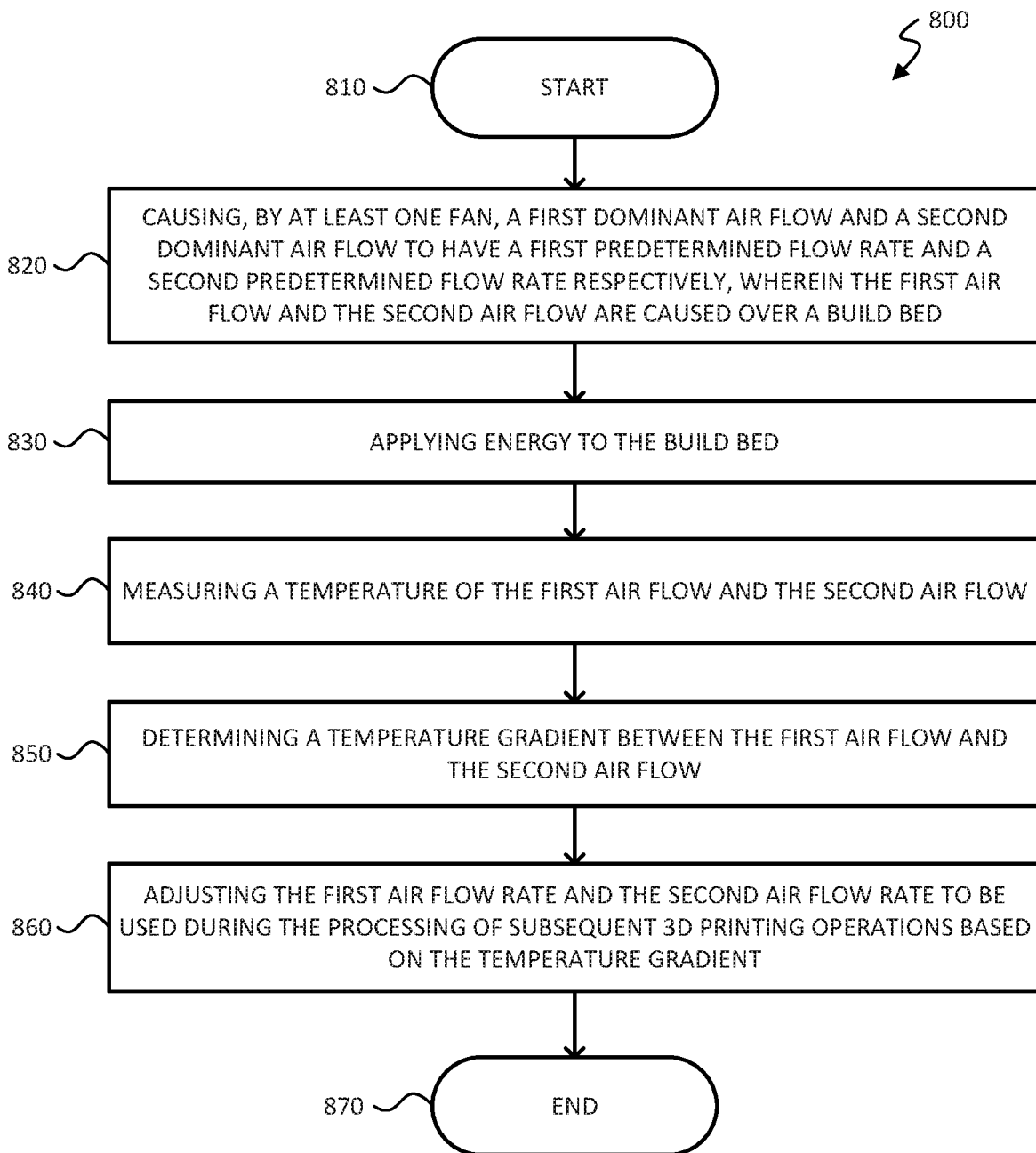


Fig. 8

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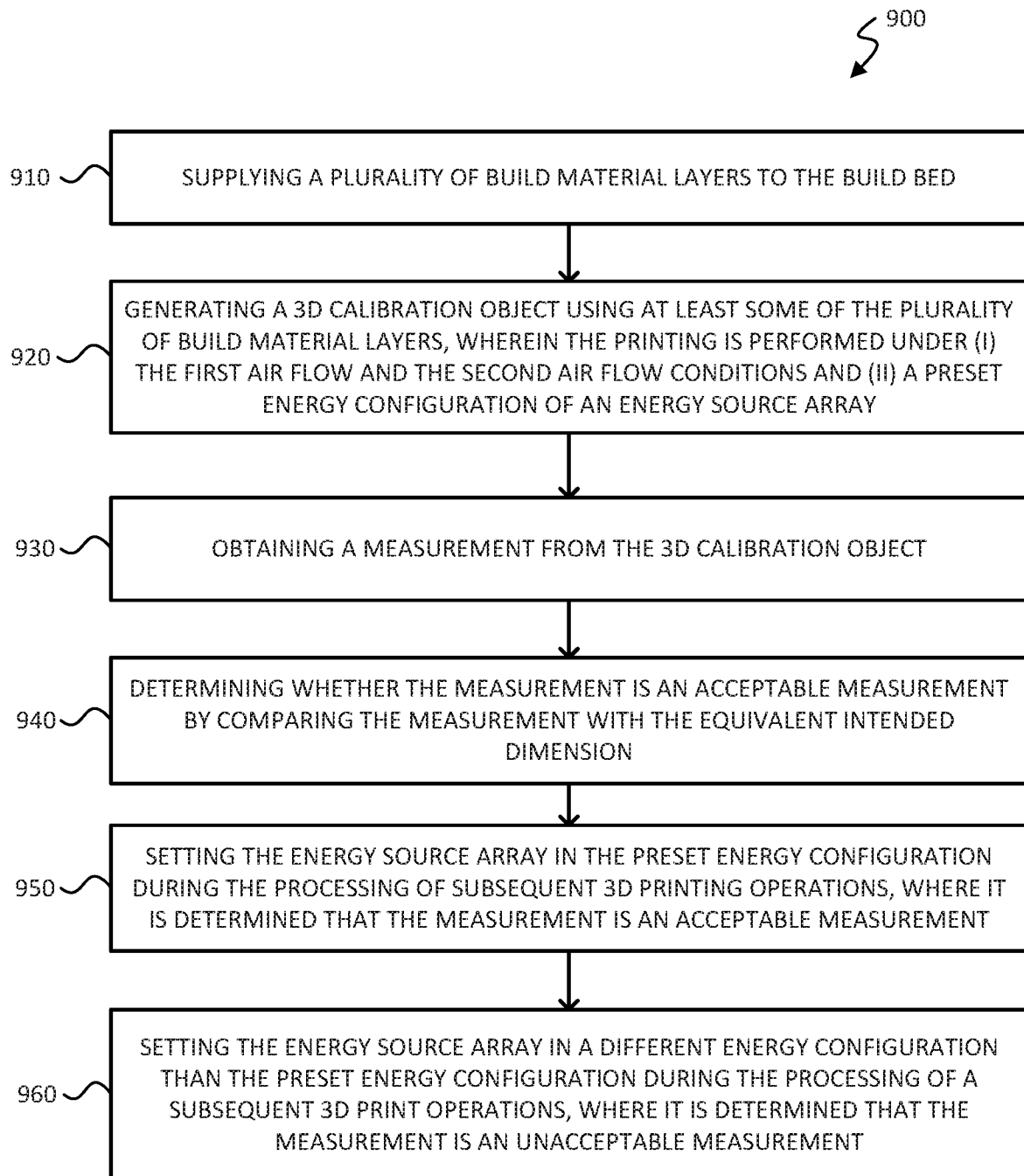


Fig. 9

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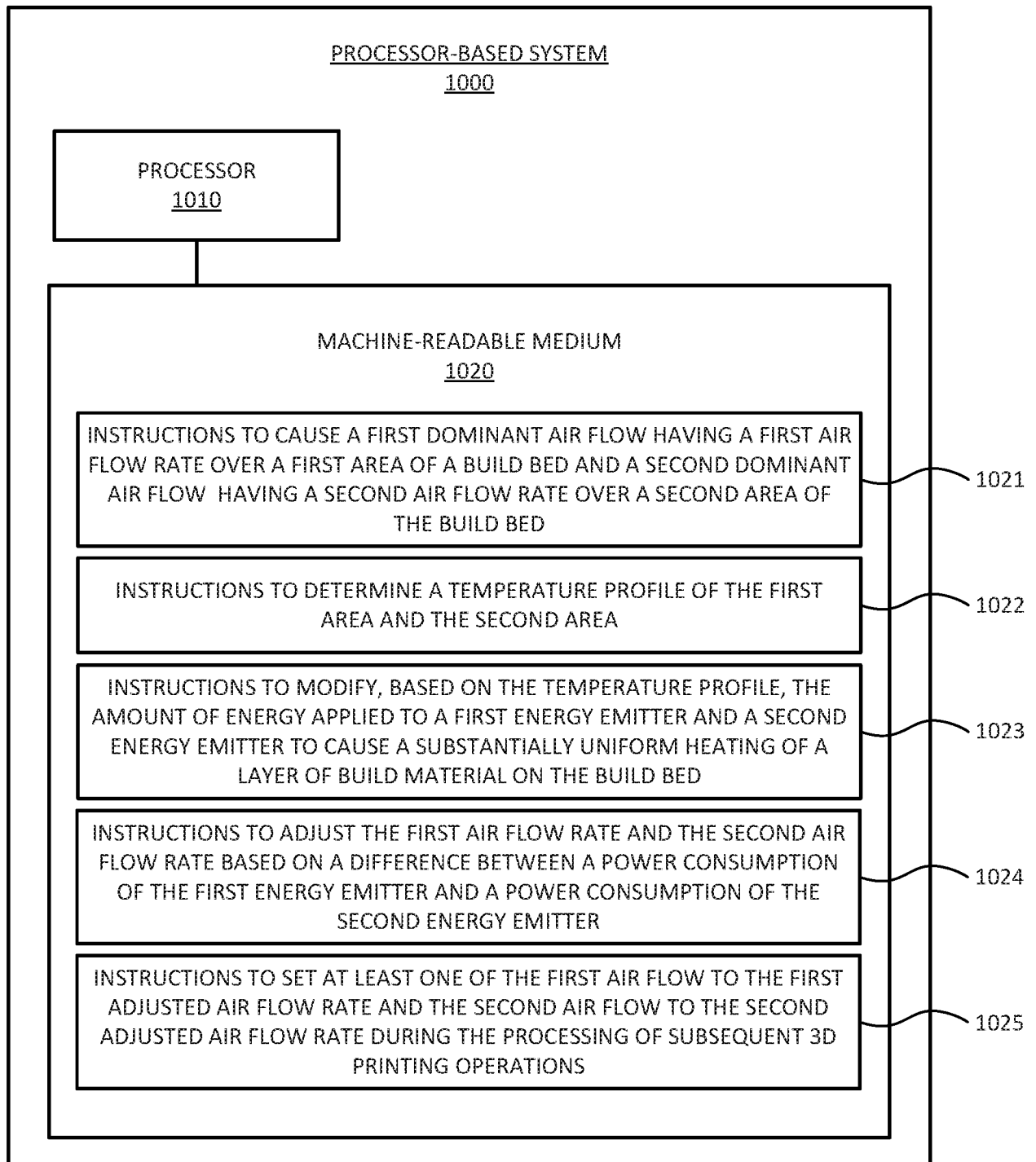


Fig. 10

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 2018/052987

A. CLASSIFICATION OF SUBJECT MATTER				
B29C 35/16 (2006.01) B29C 64/364 (2017.01) B29C 64/393 (2017.01) B33Y 40/00 (2015.01) B33Y 50/02 (2015.01)				
According to International Patent Classification (IPC) or to both national classification and IPC				
B. FIELDS SEARCHED				
Minimum documentation searched (classification system followed by classification symbols)				
B29C 33/00, 33/02, 33/10, 35/00, 35/16, 64/00, 64/20, 64/245, 64/30, 64/364, 64/386, 64/393, 67/00, B33Y 40/00, 50/00, 50/02, F28D 15/00, 15/02				
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)				
PatSearch, Espacenet, USPTO, Google				
C. DOCUMENTS CONSIDERED TO BE RELEVANT				
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.		
A	US 2015/0190966 A1 (MAKERBOT INDUSTRIES, LLC) 09.07.2015	1-15		
A	WO 2018/143956 A1 (HEWLETT-PACKARD DEVELOPMENT COMPANY, L.P.) 09.08.2018	1-15		
A	WO 2017/184002 A1 (OMNI3D SP Z O O) 26.10.2017	1-15		
A	WO 2018/167773 A1 (ZUTA-CORE LTD.) 20.09.2018	1-15		
☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.				
<table border="0"> <tr> <td style="vertical-align: top;"> * 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 document 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 </td> <td style="vertical-align: top;"> “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 </td> </tr> </table>			* 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 document 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
* 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 document 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		
24 May 2019 (24.05.2019)		30 May 2019 (30.05.2019)		
Name and mailing address of the ISA/RU: Federal Institute of Industrial Property, Berezhkovskaya nab., 30-1, Moscow, G-59, GSP-3, Russia, 125993 Facsimile No: (8-495) 531-63-18, (8-499) 243-33-37		Authorized officer D. Starshinov Telephone No. 8 (495)-531-64-81		