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(54) ADDITIVE MANUFACTURING SYSTEM

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(21) Appl. No.: **19/052,710**

(22) Filed: **Feb. 13, 2025**

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Publication Classification

(51) **Int. Cl.**

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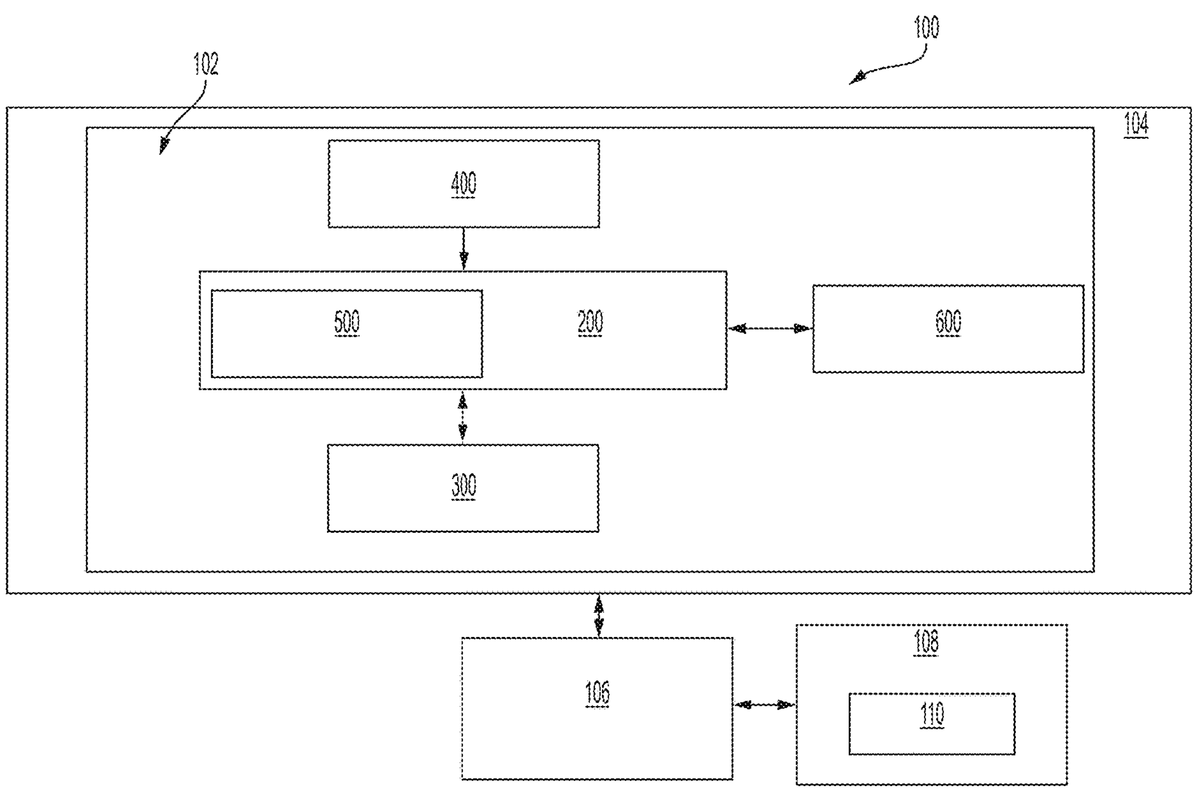
B29C 64/268	(2017.01)
B29C 64/393	(2017.01)
B33Y 30/00	(2015.01)
B33Y 50/02	(2015.01)

(52) **U.S. Cl.**
CPC ***B29C 64/232*** (2017.08); ***B29C 64/245*** (2017.08); ***B29C 64/268*** (2017.08); ***B29C 64/393*** (2017.08); ***B33Y 30/00*** (2014.12); ***B33Y 50/02*** (2014.12)

(57) **ABSTRACT**

An additive manufacturing system for manufacturing a component, the additive manufacturing system comprising a frame, an additive manufacturing machine disposed on the frame, a processor disposed on the frame and electrically coupled to the additive manufacturing system, a memory unit electrically coupled to the processor and containing instructions to control the additive manufacturing system.



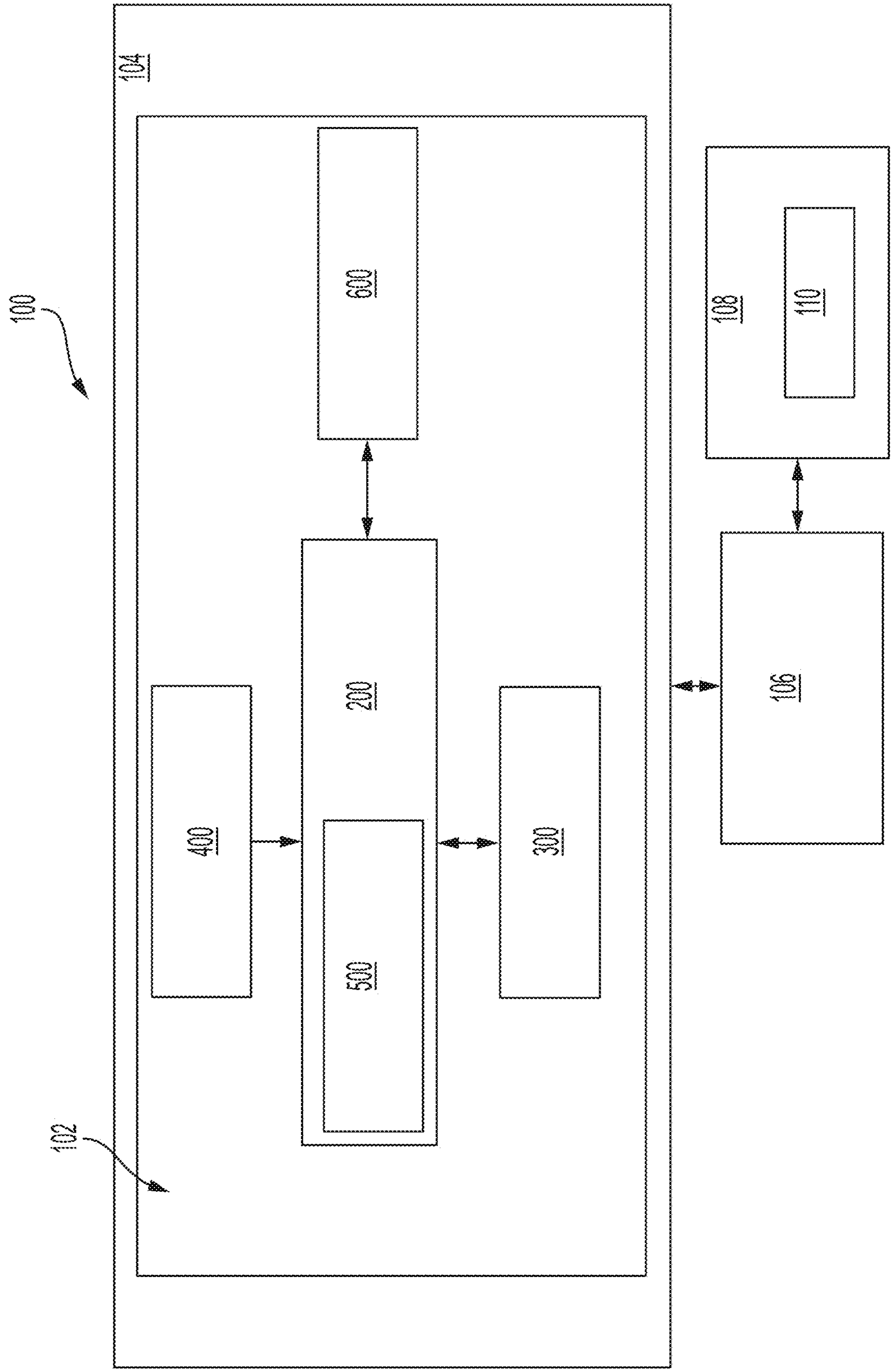


FIG. 1

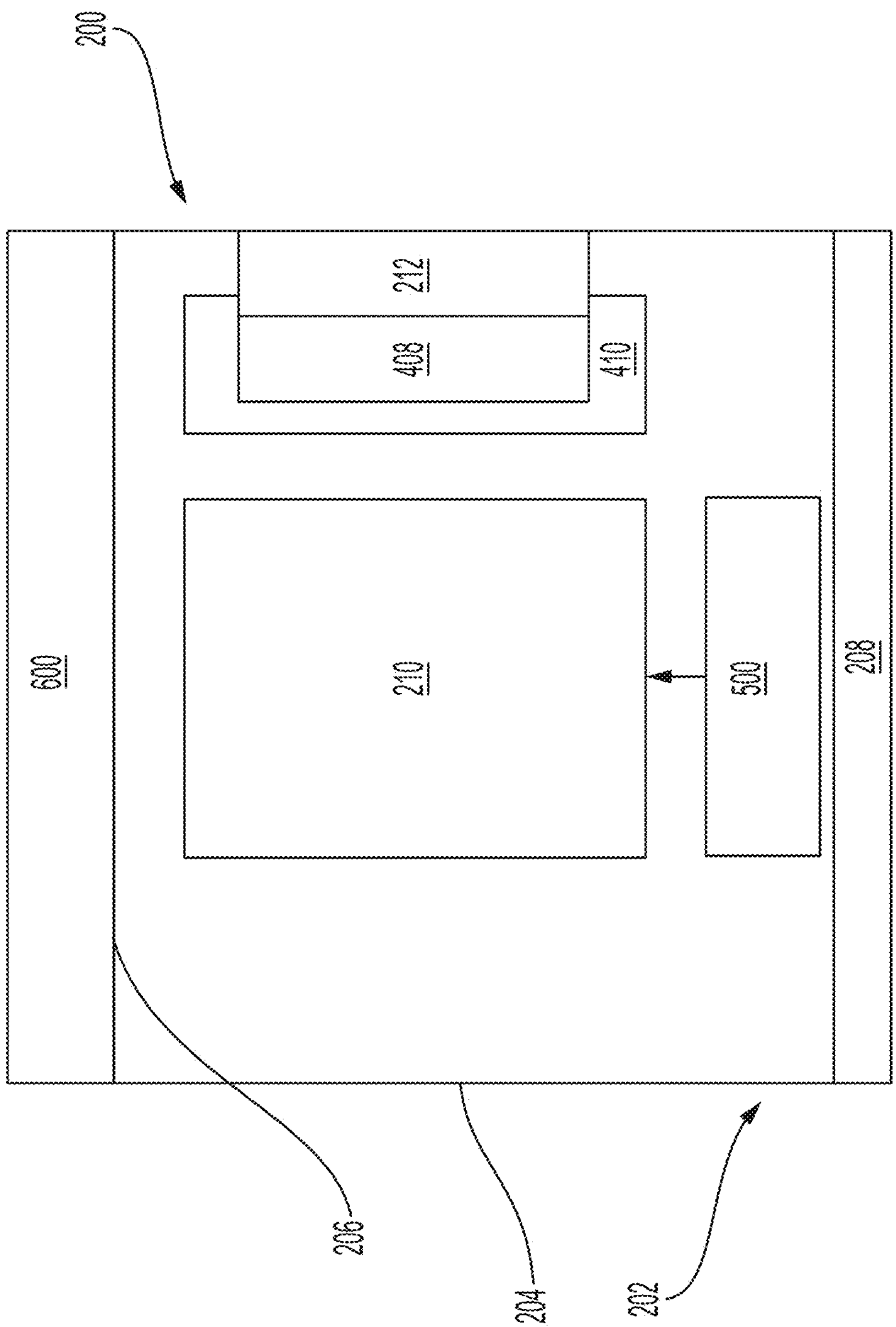


FIG. 2A

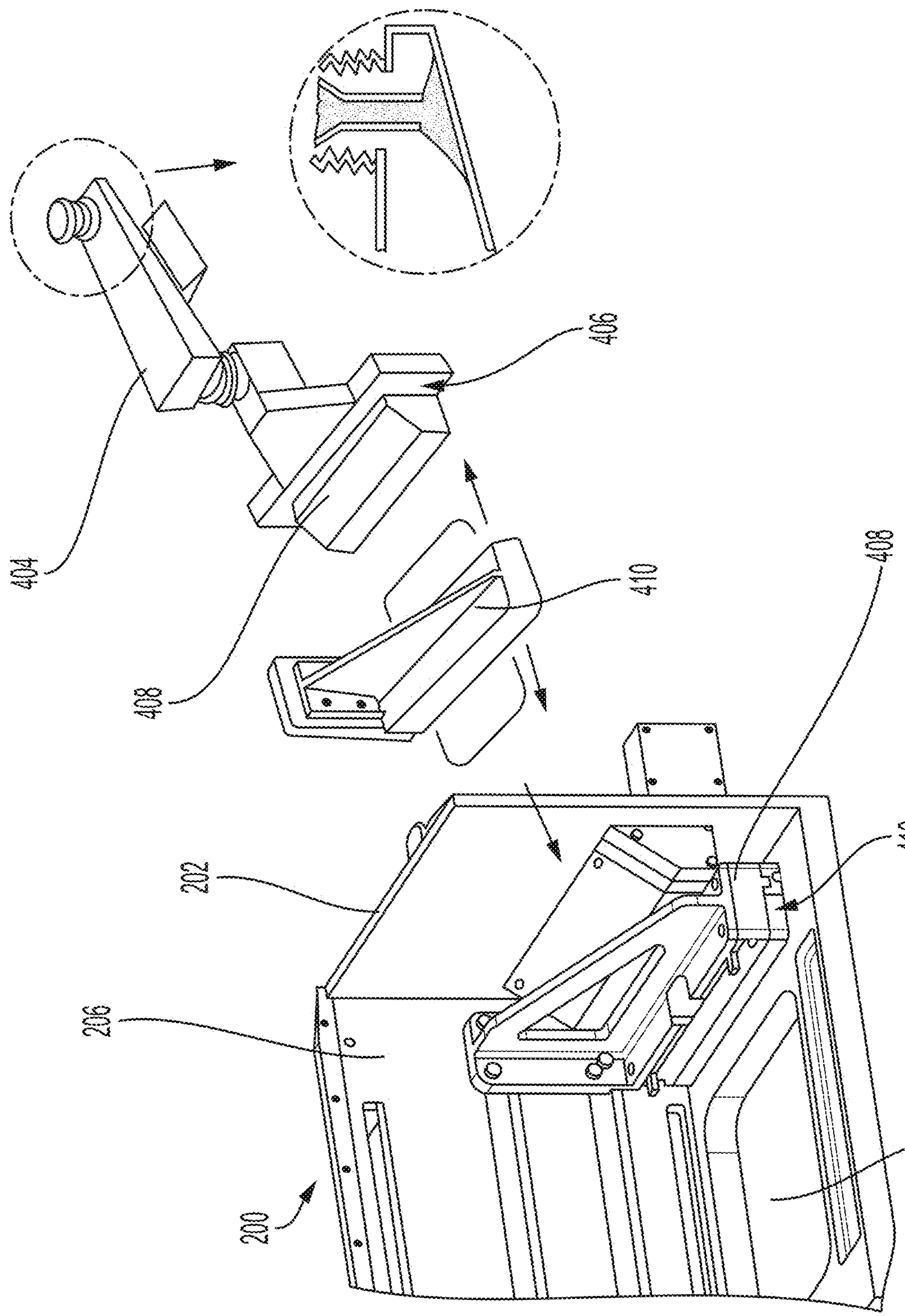


FIG. 2B

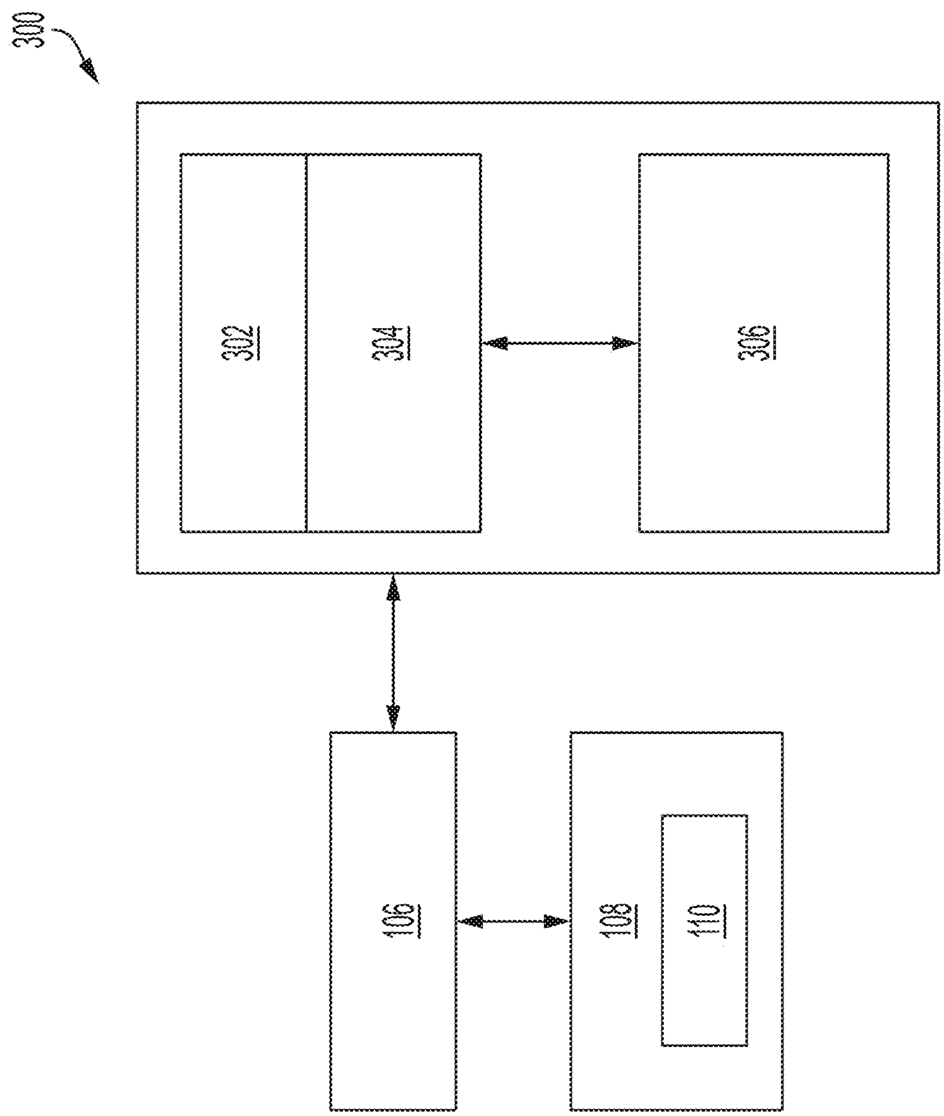


FIG. 3A

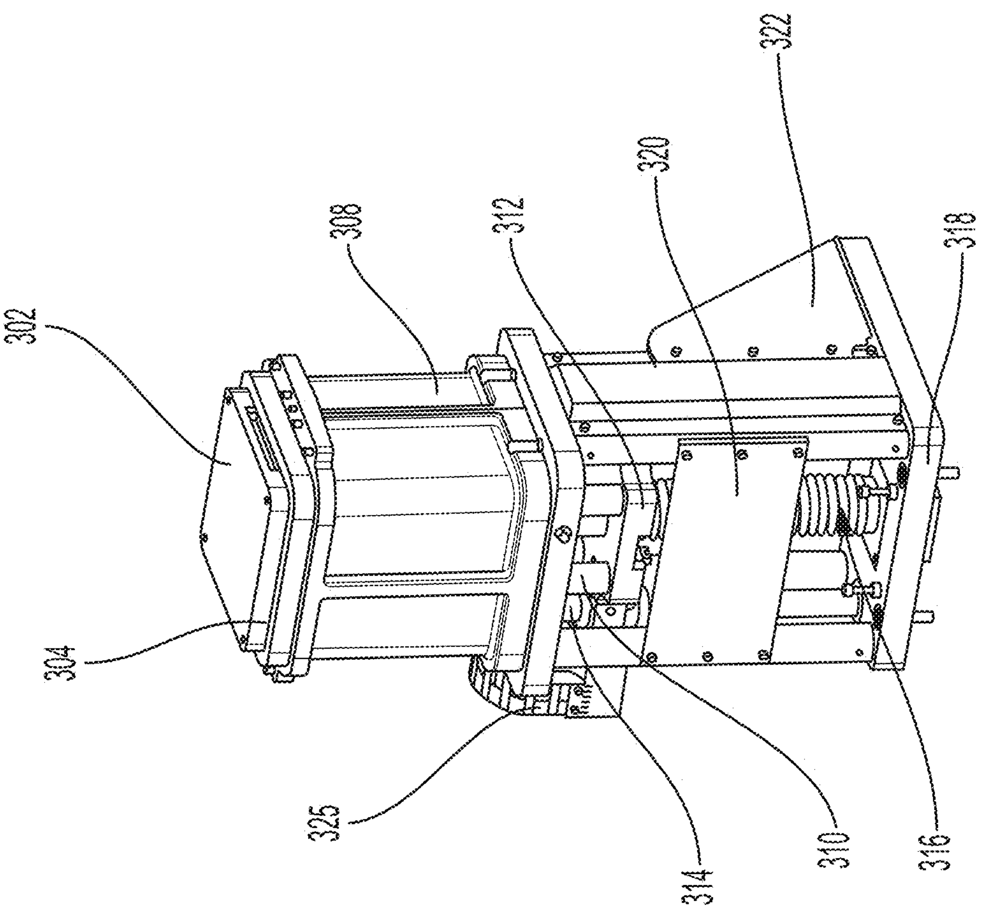


FIG. 3C

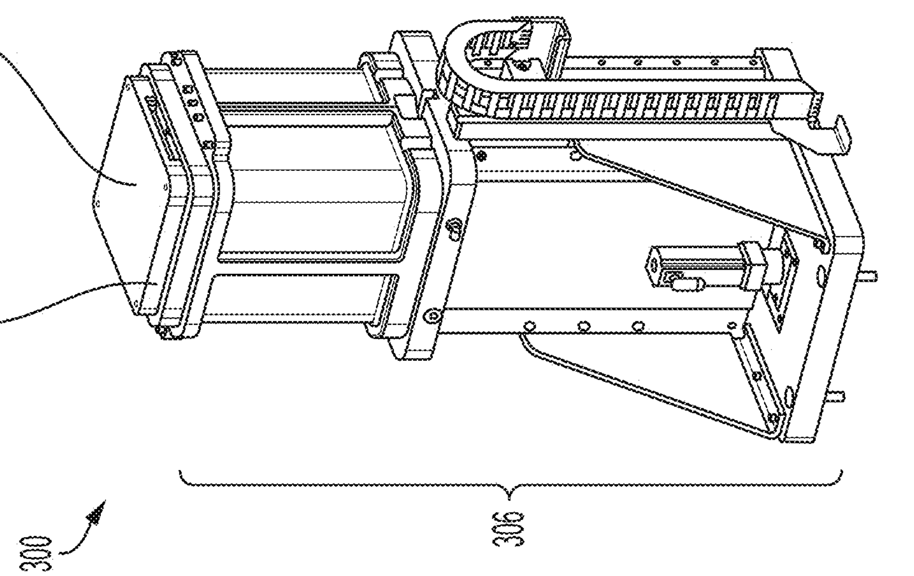


FIG. 3B

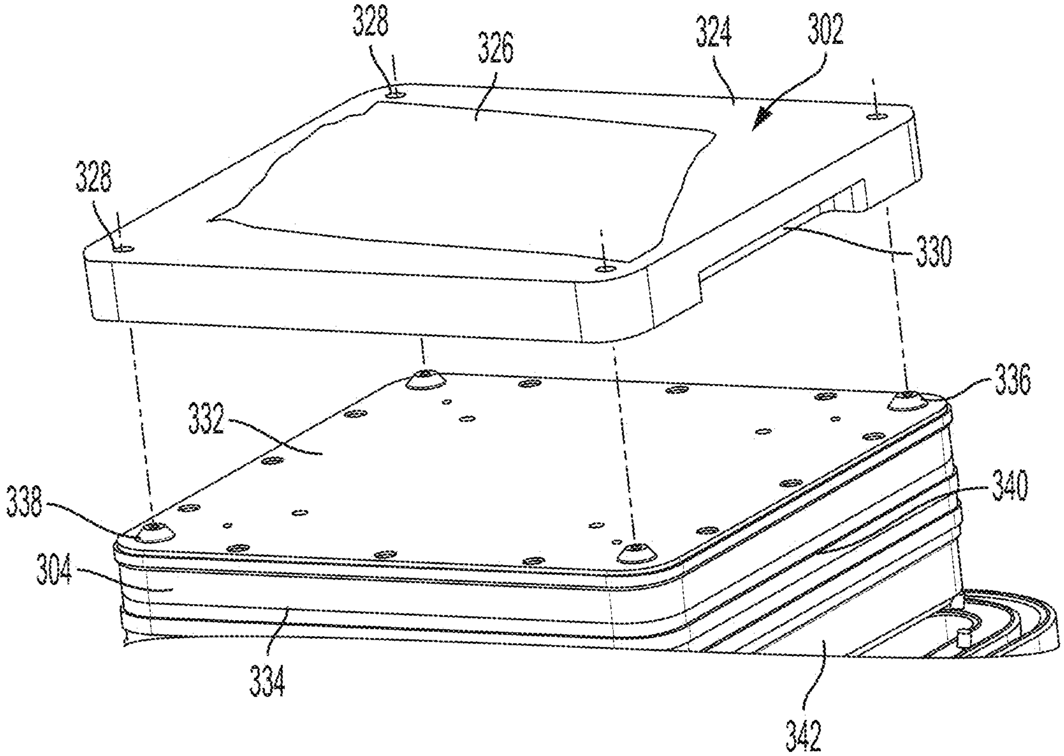


FIG. 3D-1

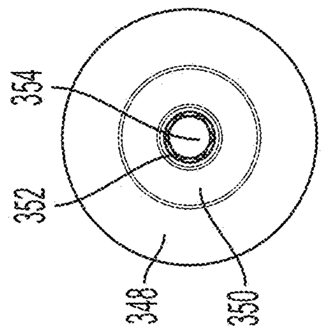


FIG. 3D-3

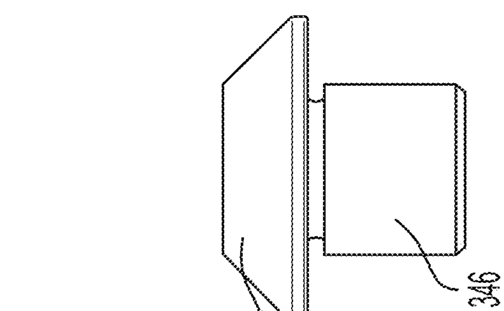


FIG. 3D-2

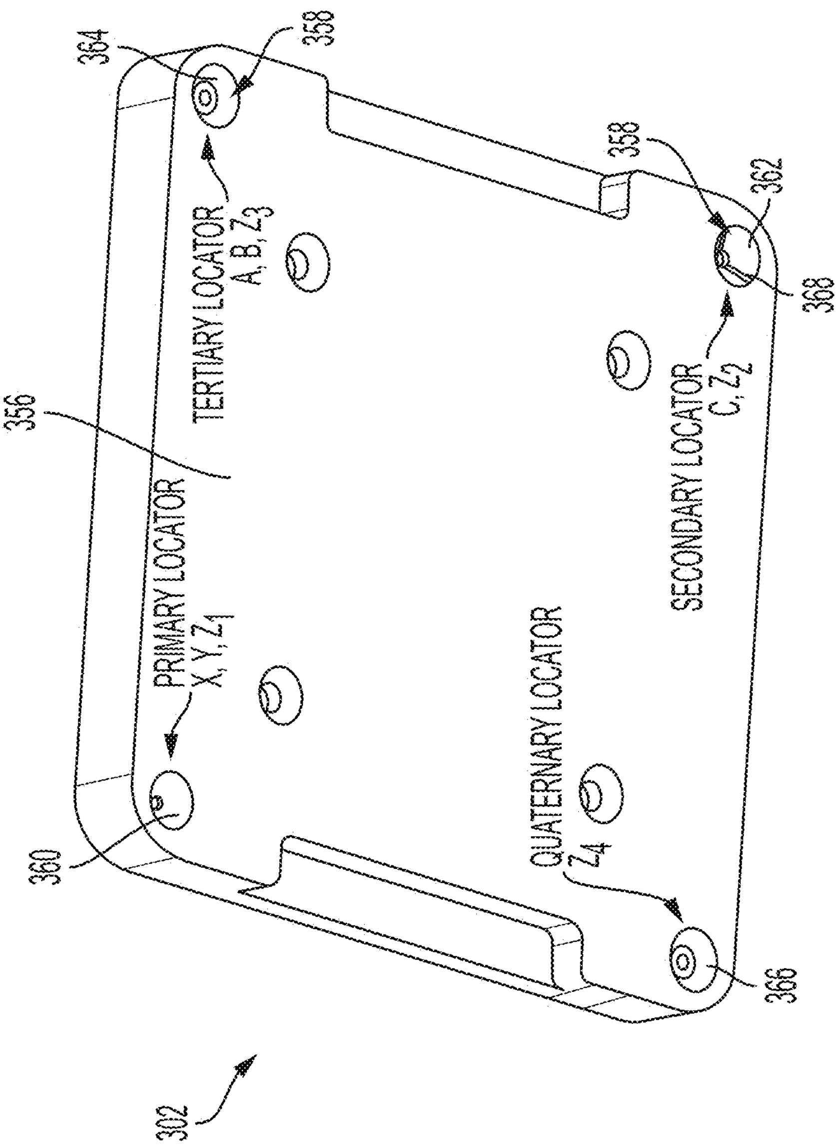

364
358
358
362
368
TERTIARY LOCATOR
A, B, Z3
SECONDARY LOCATOR
C, Z2
356
PRIMARY LOCATOR
X, Y, Z1
QUATERNARY LOCATOR
Z4
360
366
302

FIG. 3D-4

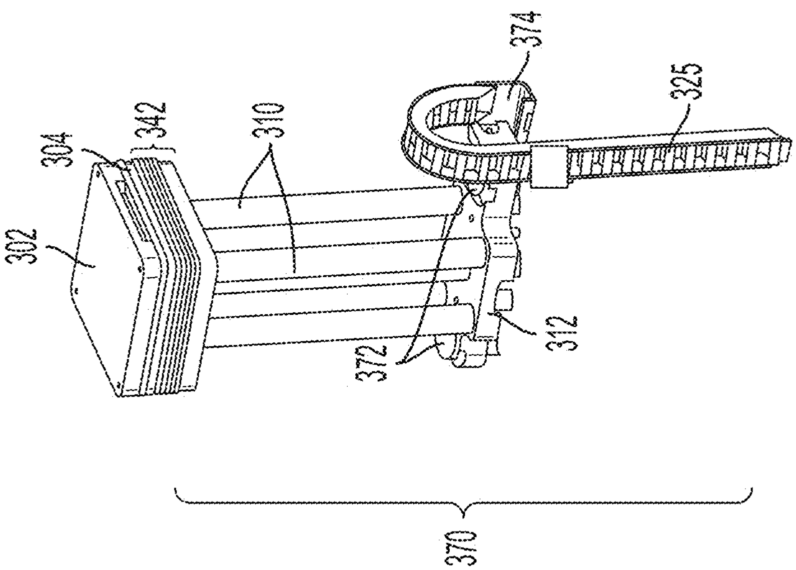


FIG. 3E

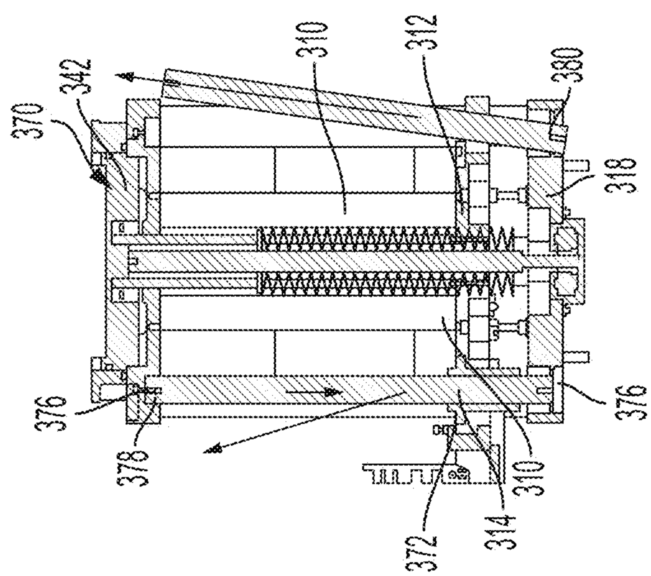


FIG. 3F

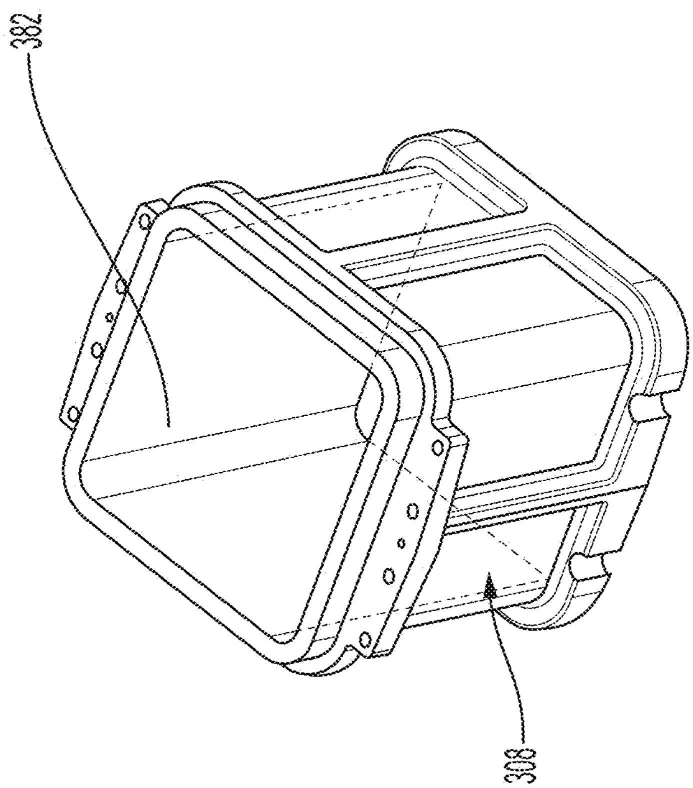


FIG. 3G

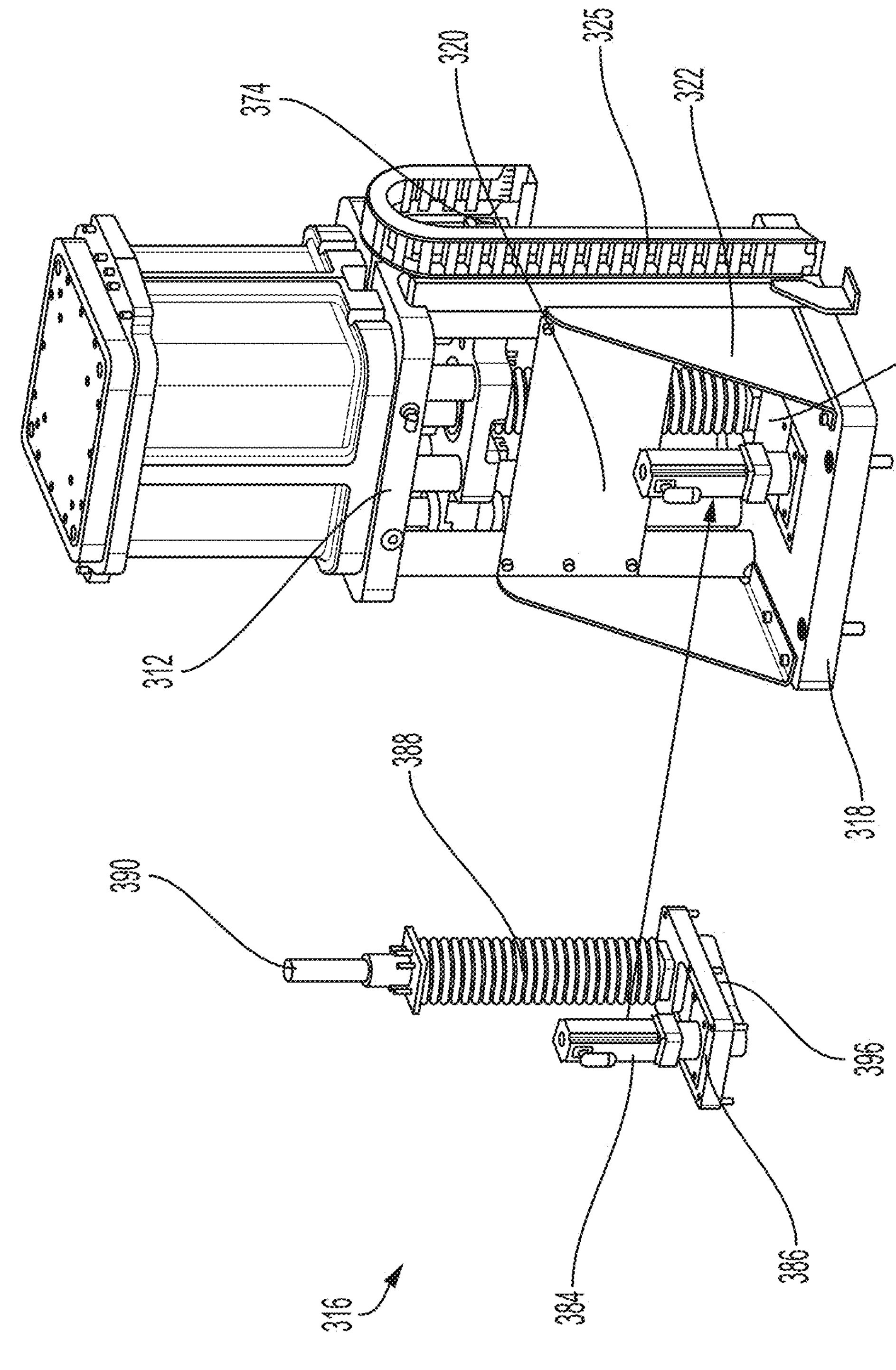


FIG. 3H

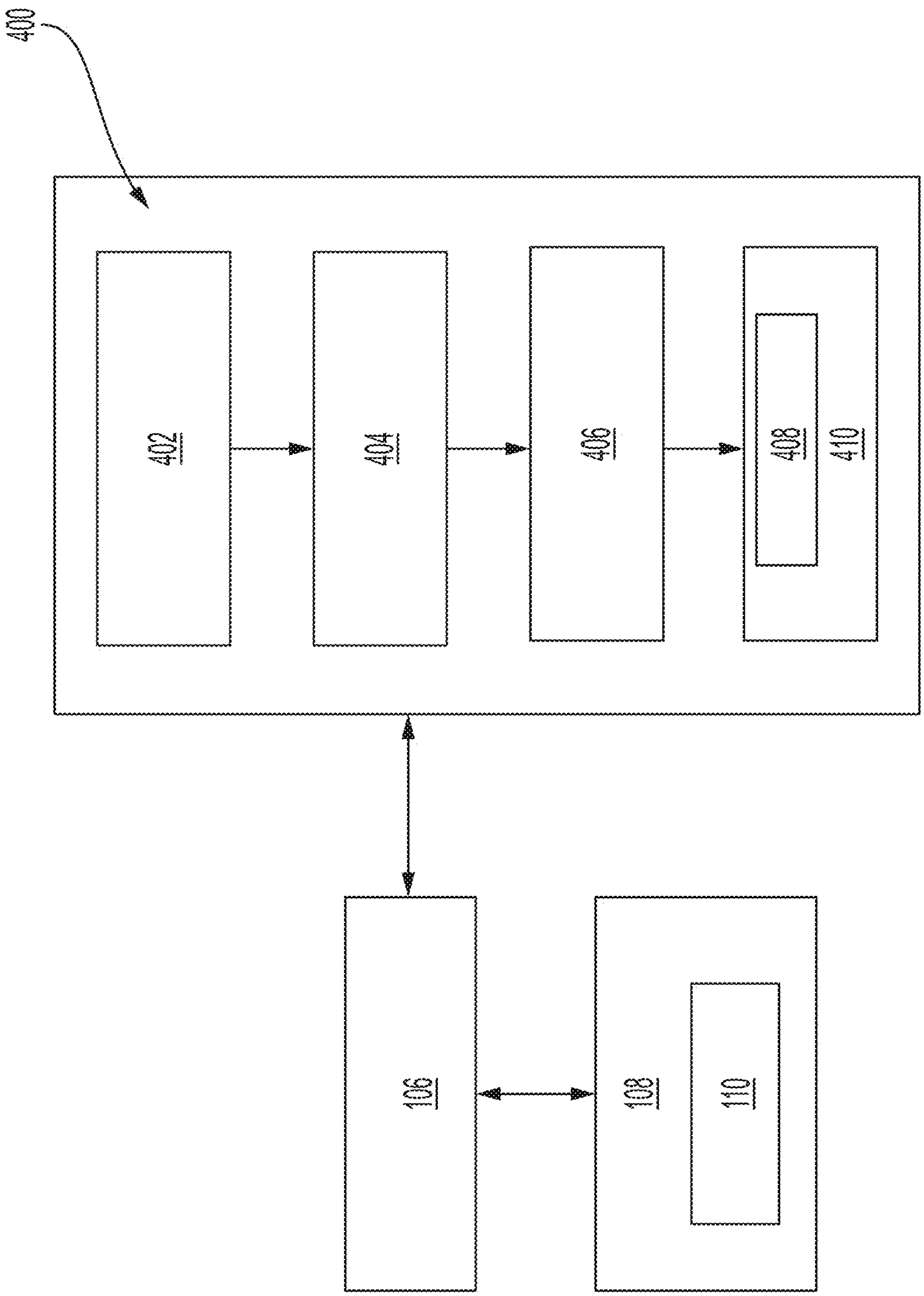


FIG. 4A

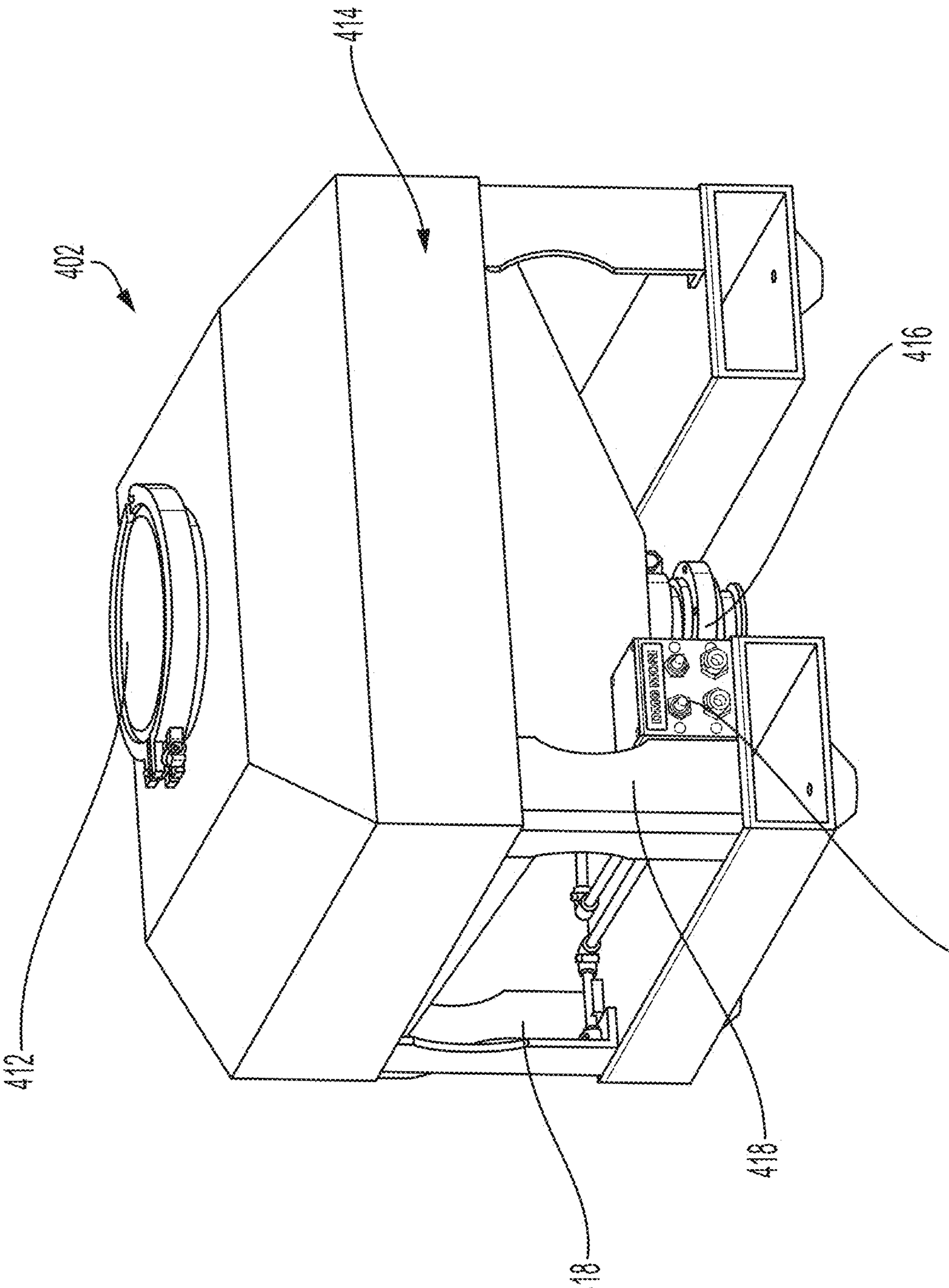


FIG. 4B

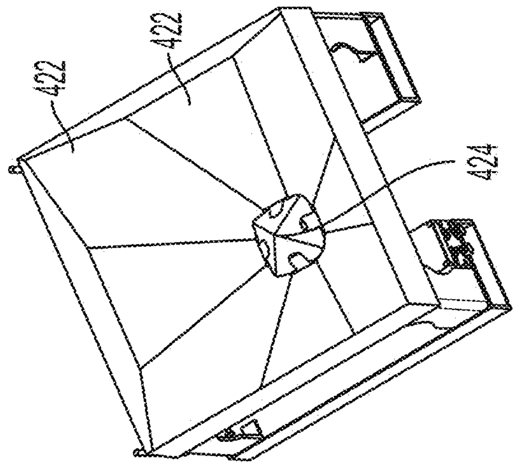


FIG. 4C-3

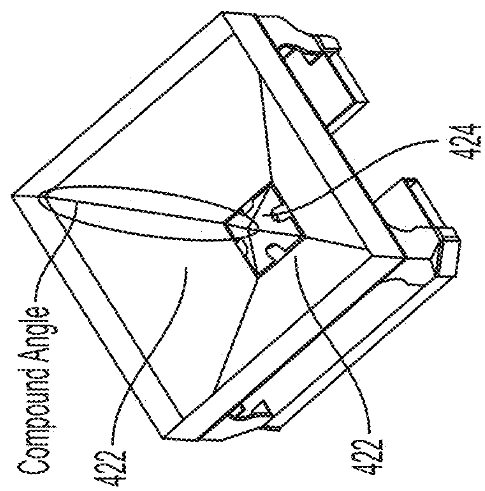


FIG. 4C-2

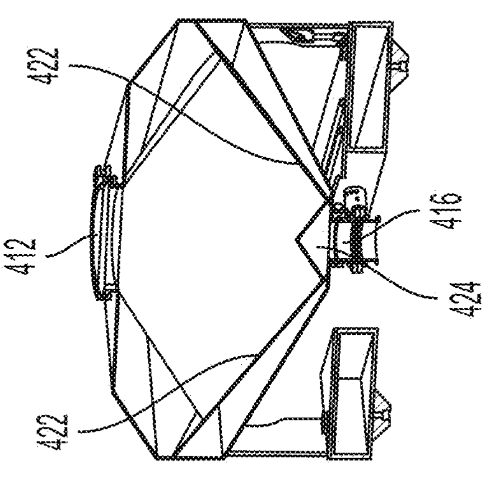


FIG. 4C-1

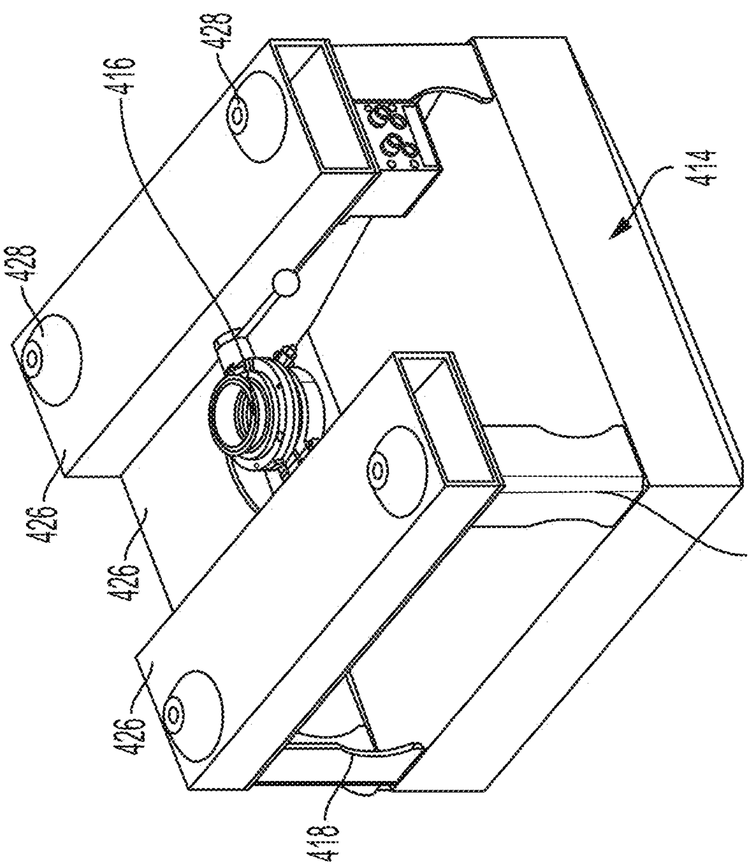


FIG. 4C-4

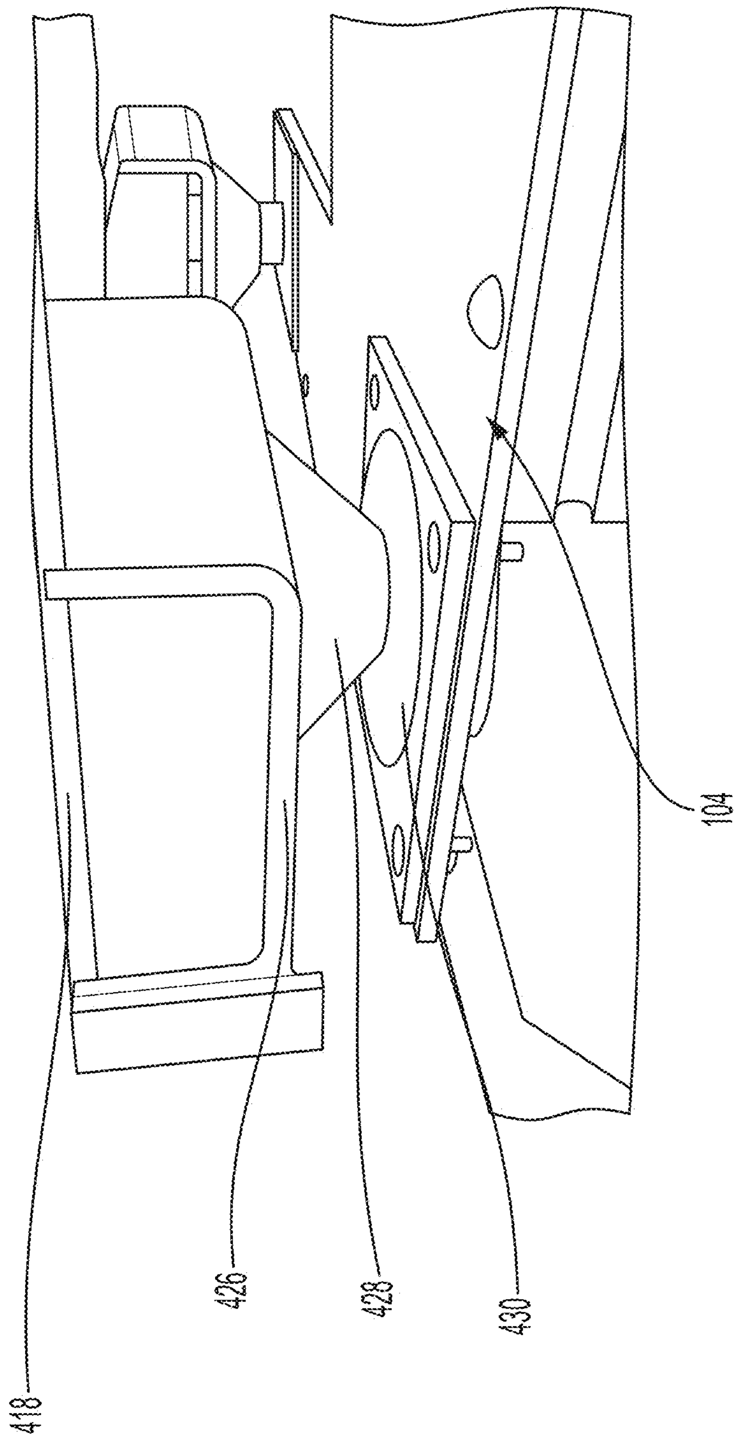


FIG. 4C-5

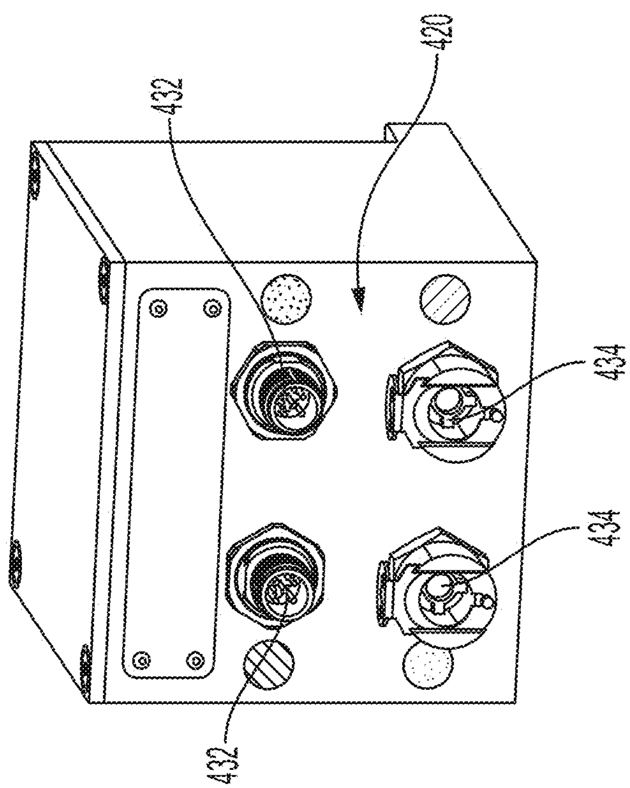


FIG. 4C-6

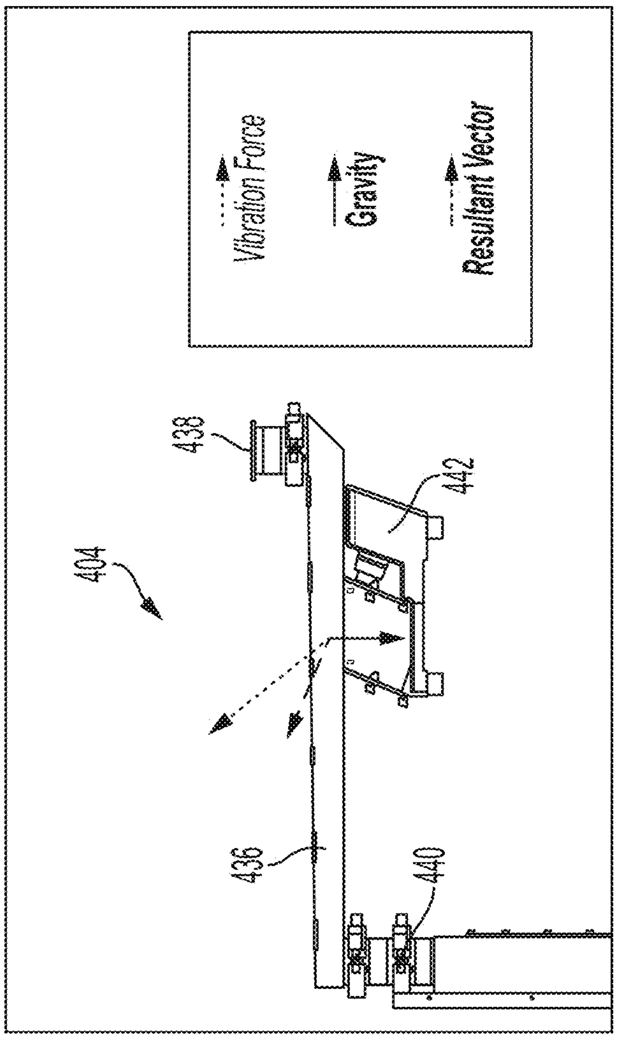

Vibration Force
Gravity
Resultant Vector
438
442
404
436
440

FIG. 4D-1

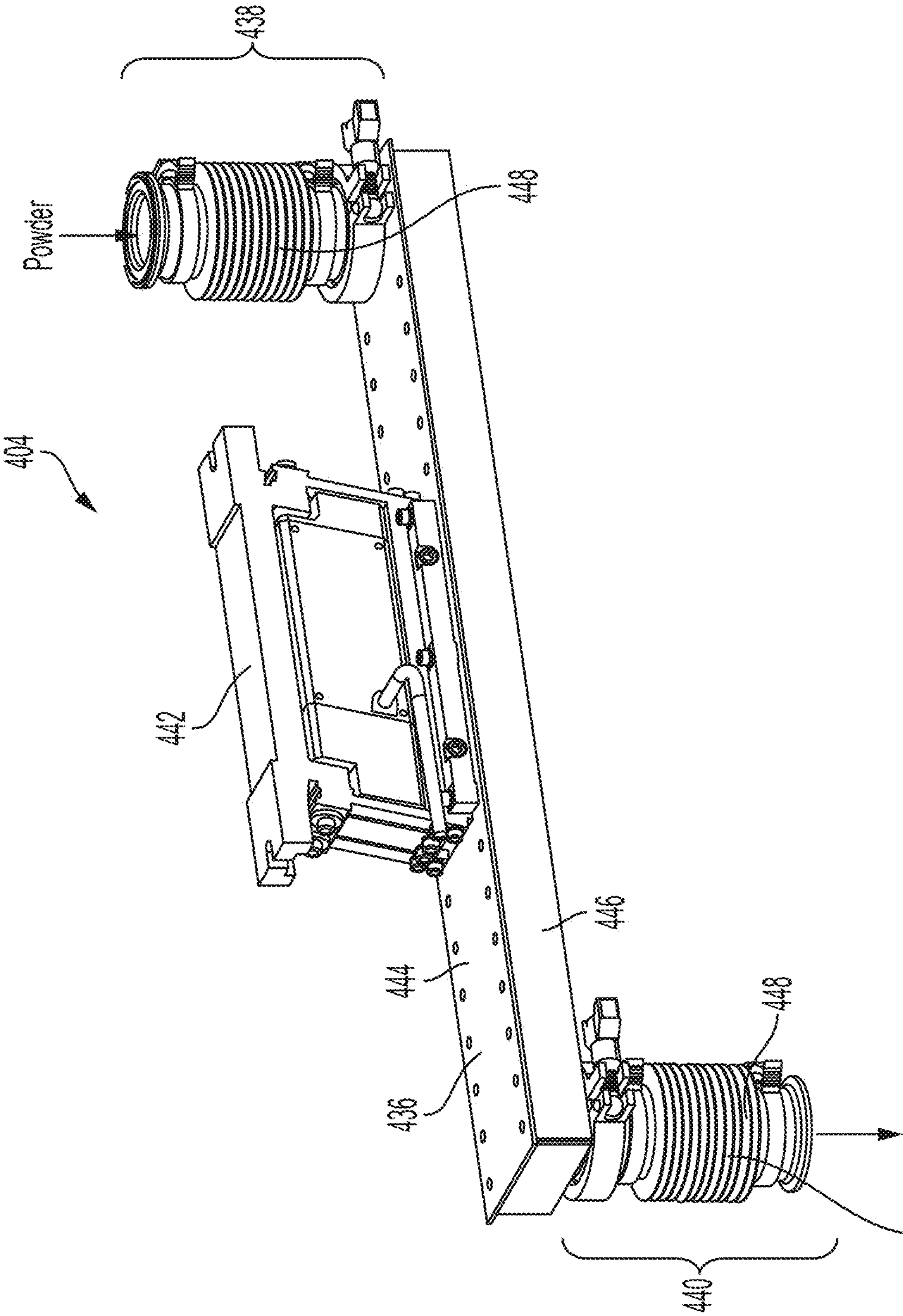


FIG. 4D-2

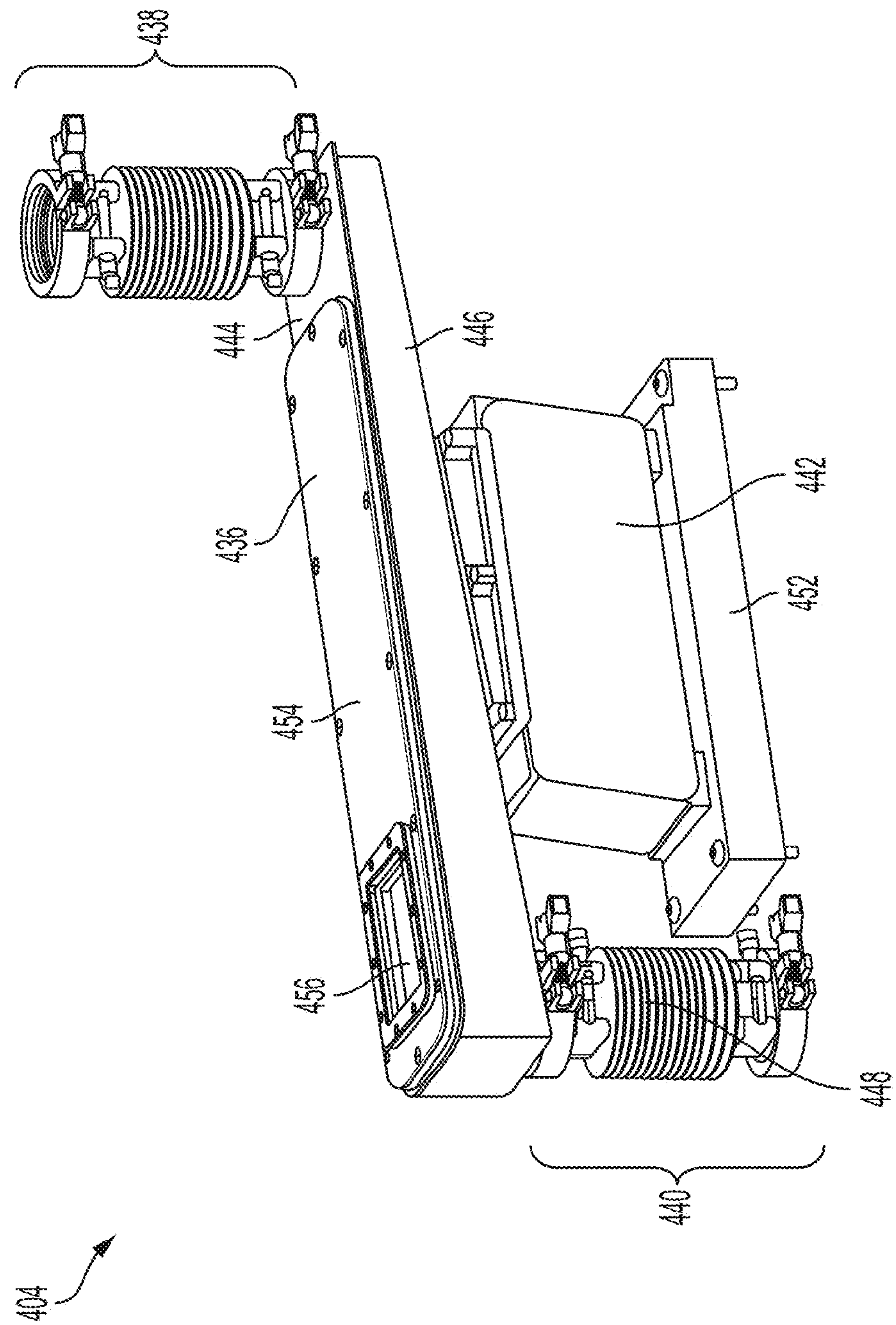


FIG. 4D-3

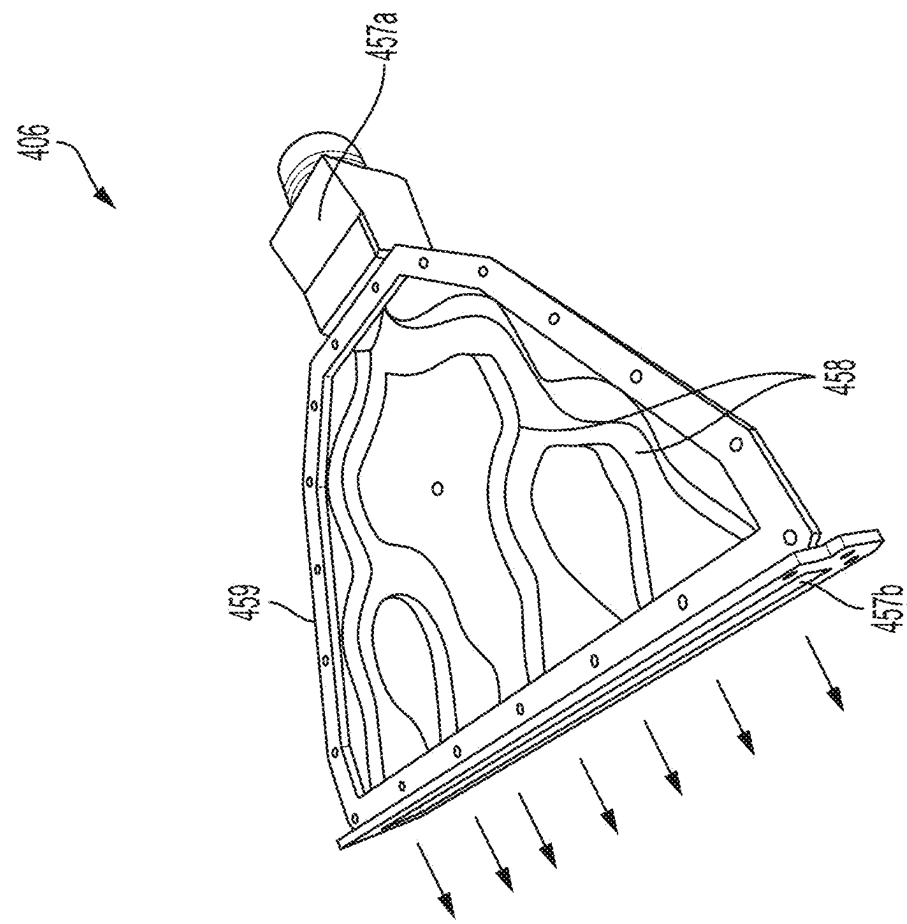


FIG. 4E

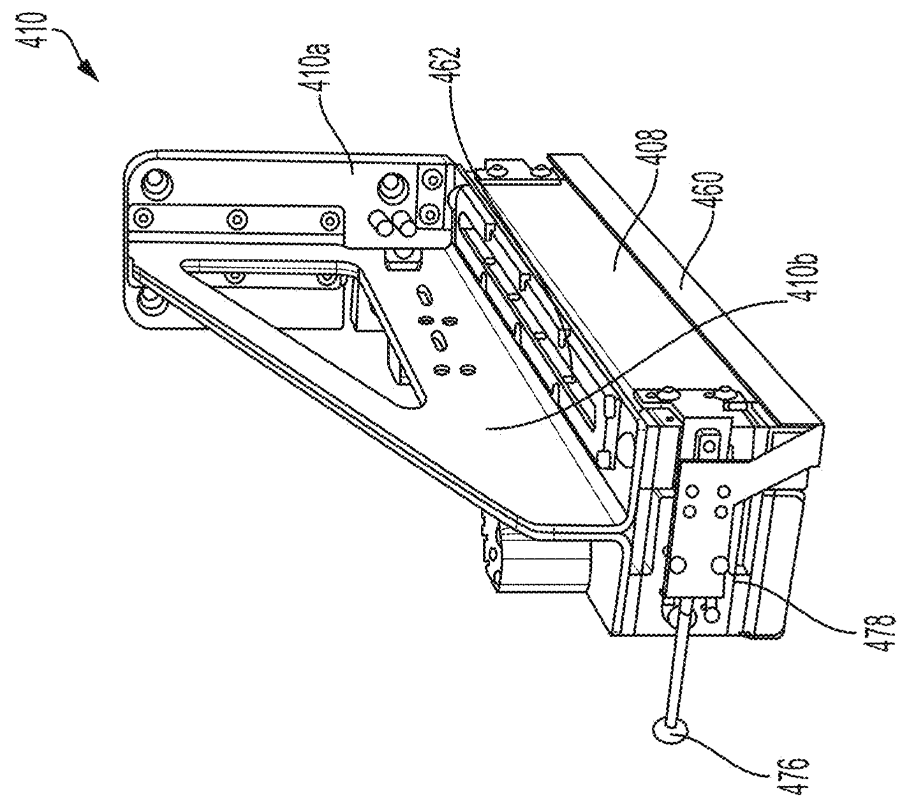


FIG. 4F-1

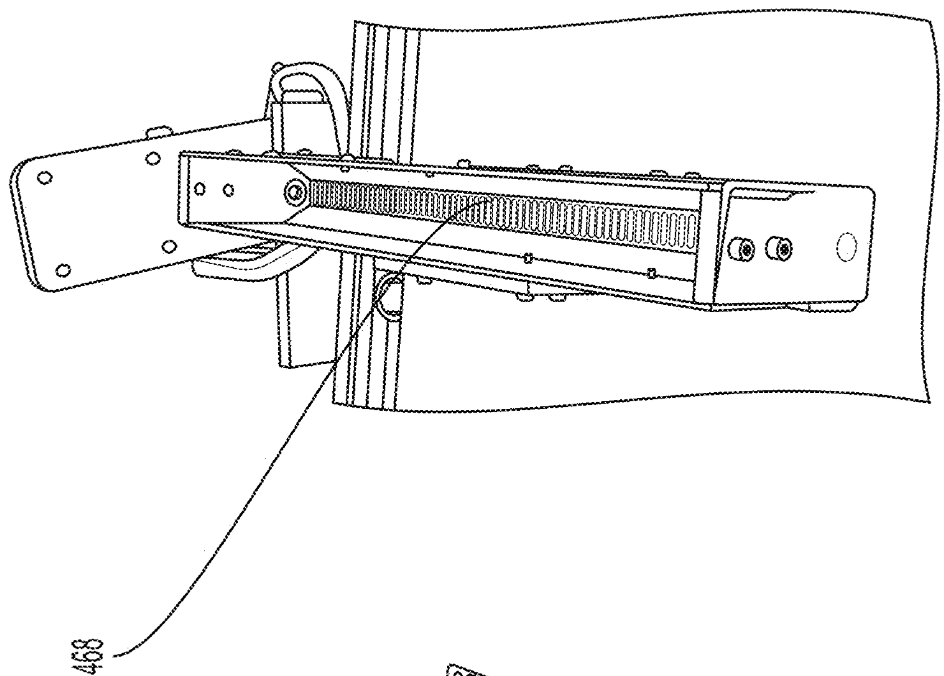


FIG. 4F-3

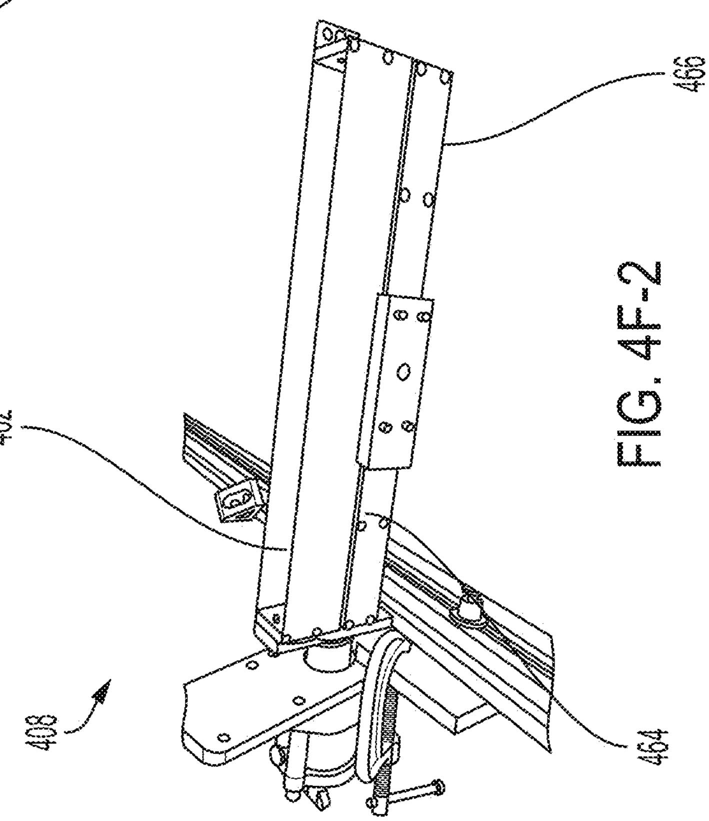


FIG. 4F-2

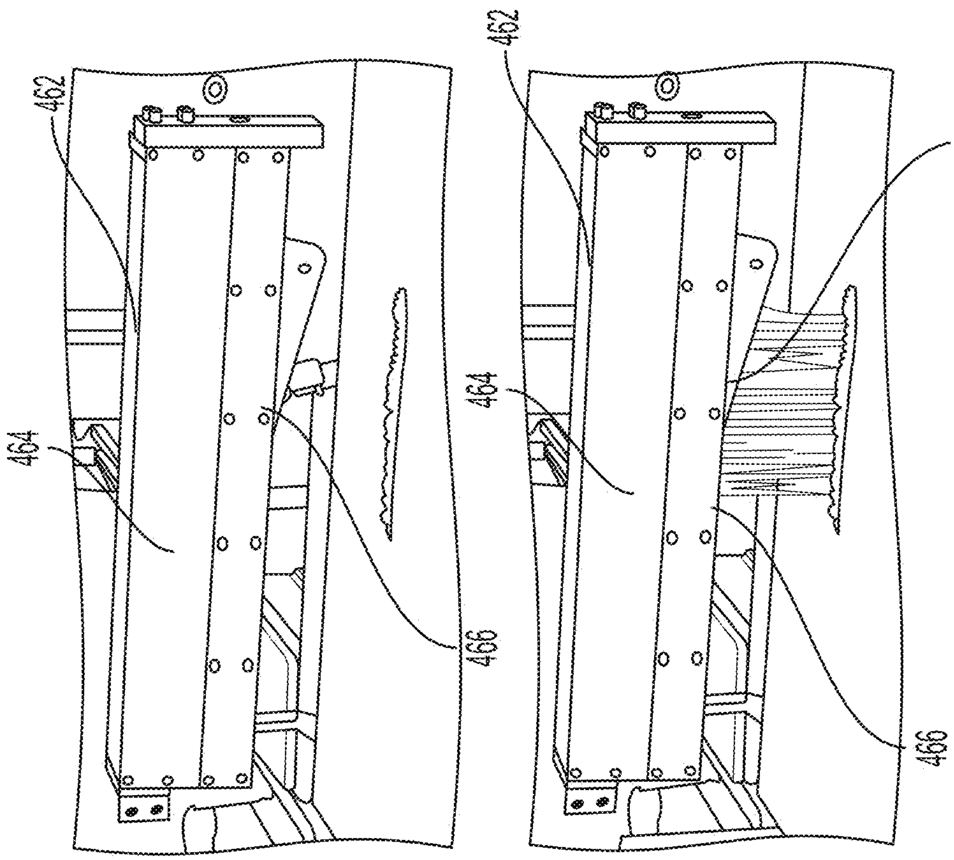


FIG. 4F-5

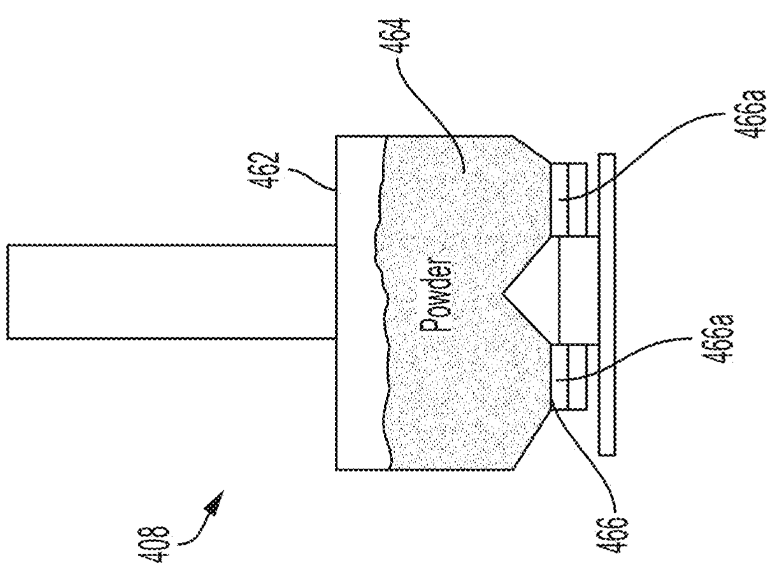


FIG. 4F-4

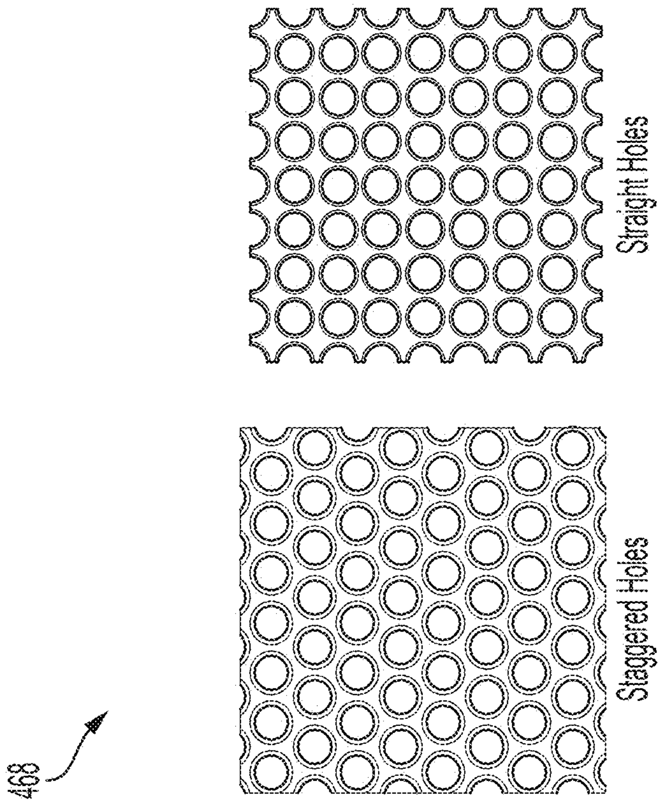


FIG. 4F-6

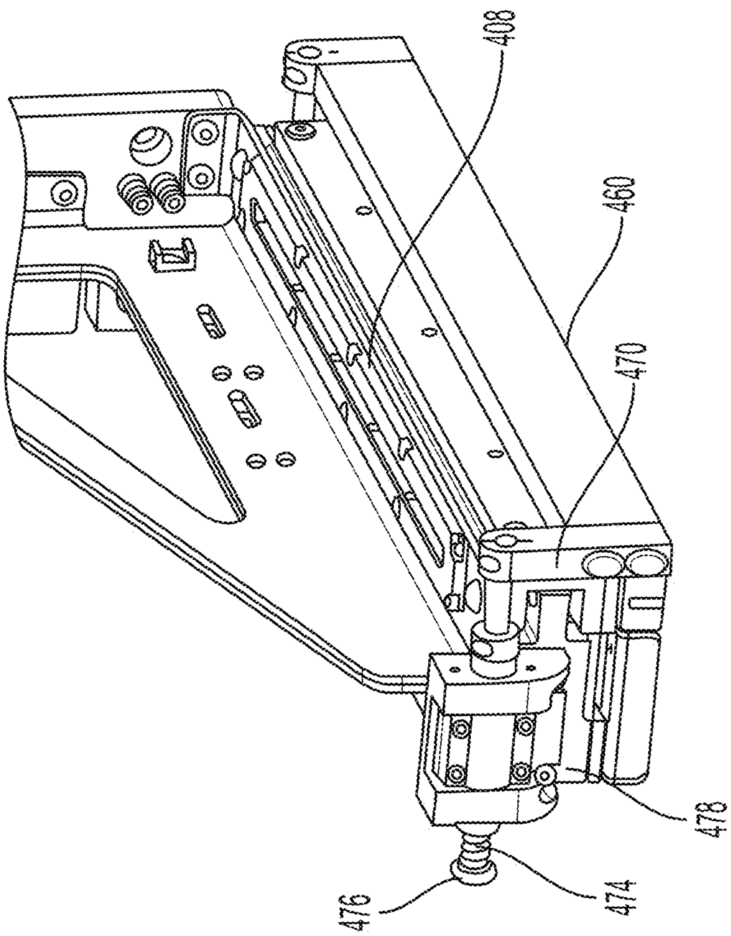


FIG. 4F-7

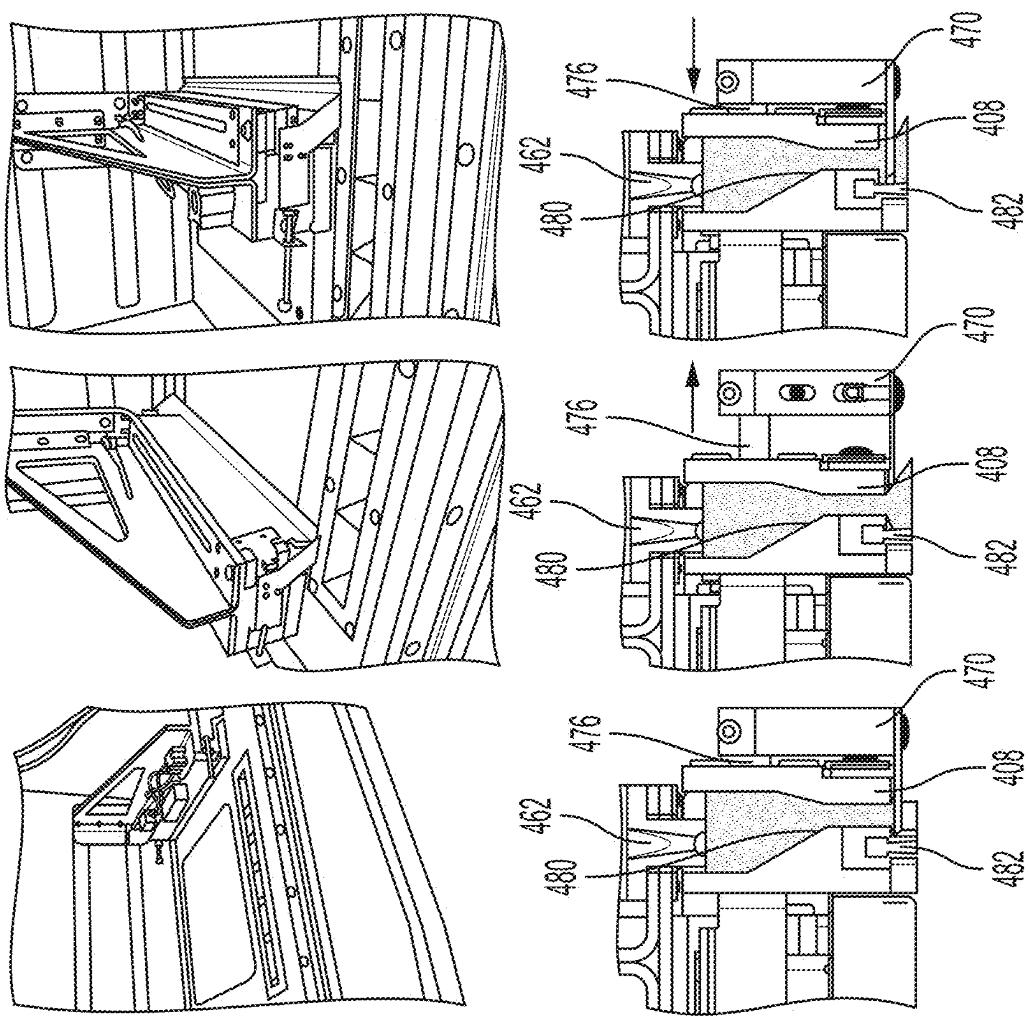

470
476
462
408
480
482
470
476
462
408
480
482
470
476
462
408
480
482

FIG. 4F-8

316L

Dose number	Mass of dosed powder (g)
1	13.24
2	13.24
3	13.96
4	13.31
5	13.44
6	13.69
7	13.58
8	14.09
9	13.43
10	13.20
11	13.31
12	13.19
13	13.33
14	13.31
15	14.00
16	13.50
17	13.24
18	14.09
Mean	13.51
STD	0.32
COV	2.4%
Max	14.09
Min	13.19
Range	**0.90**

FIG. 4G-1

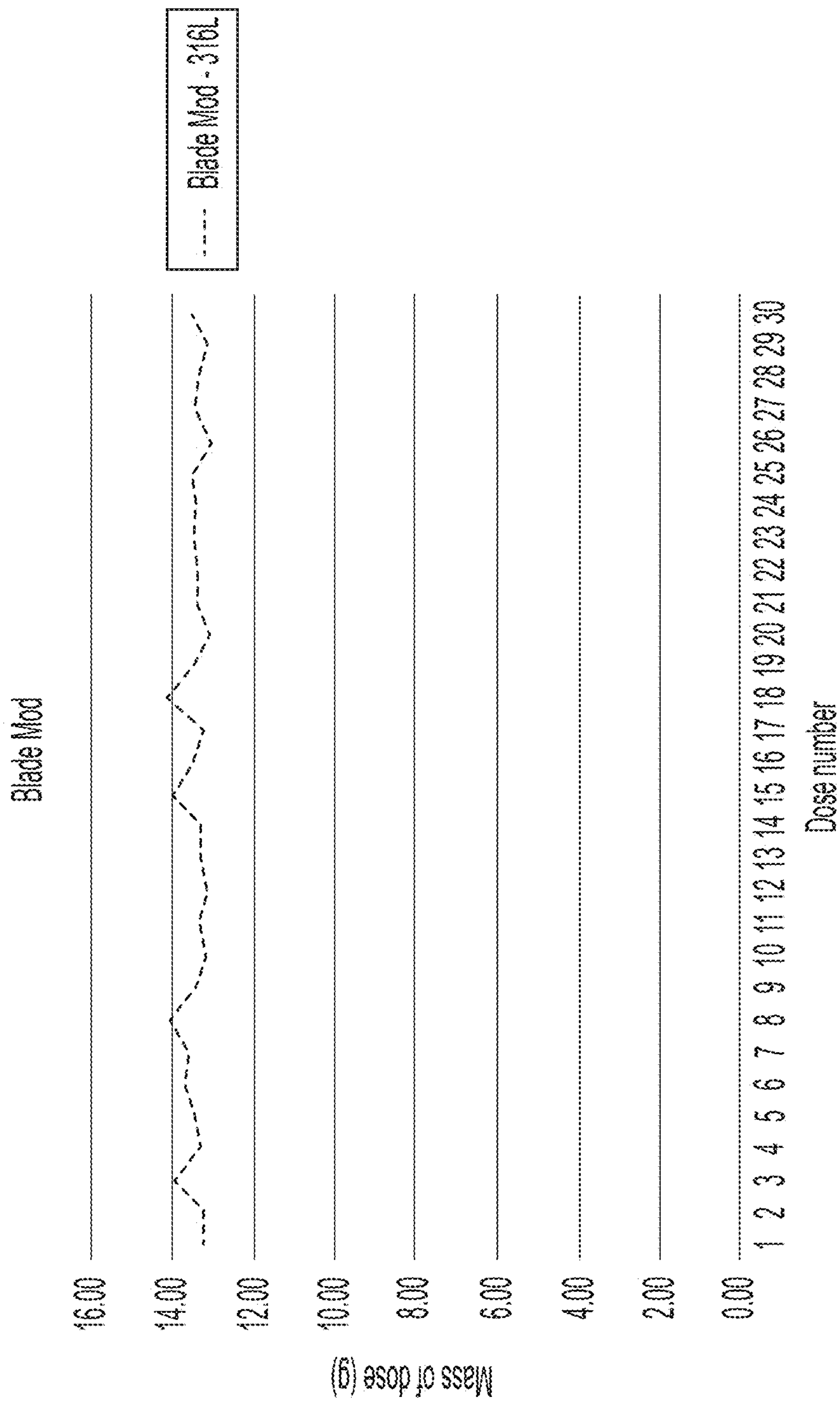


FIG. 4G-1
CONTINUED

17-4

Dose number	Mass of dosed powder (g)
1	15.15
2	14.75
3	15.00
4	14.67
5	14.85
6	14.62
7	14.71
8	14.52
9	15.94
10	14.52
11	14.64
12	14.62
13	14.43
14	14.67
15	14.66
16	14.42
Mean	14.76
STD	0.37
COV	2%
Max	15.94
Min	14.42
Range	1.52

FIG. 4G-1
CONTINUED

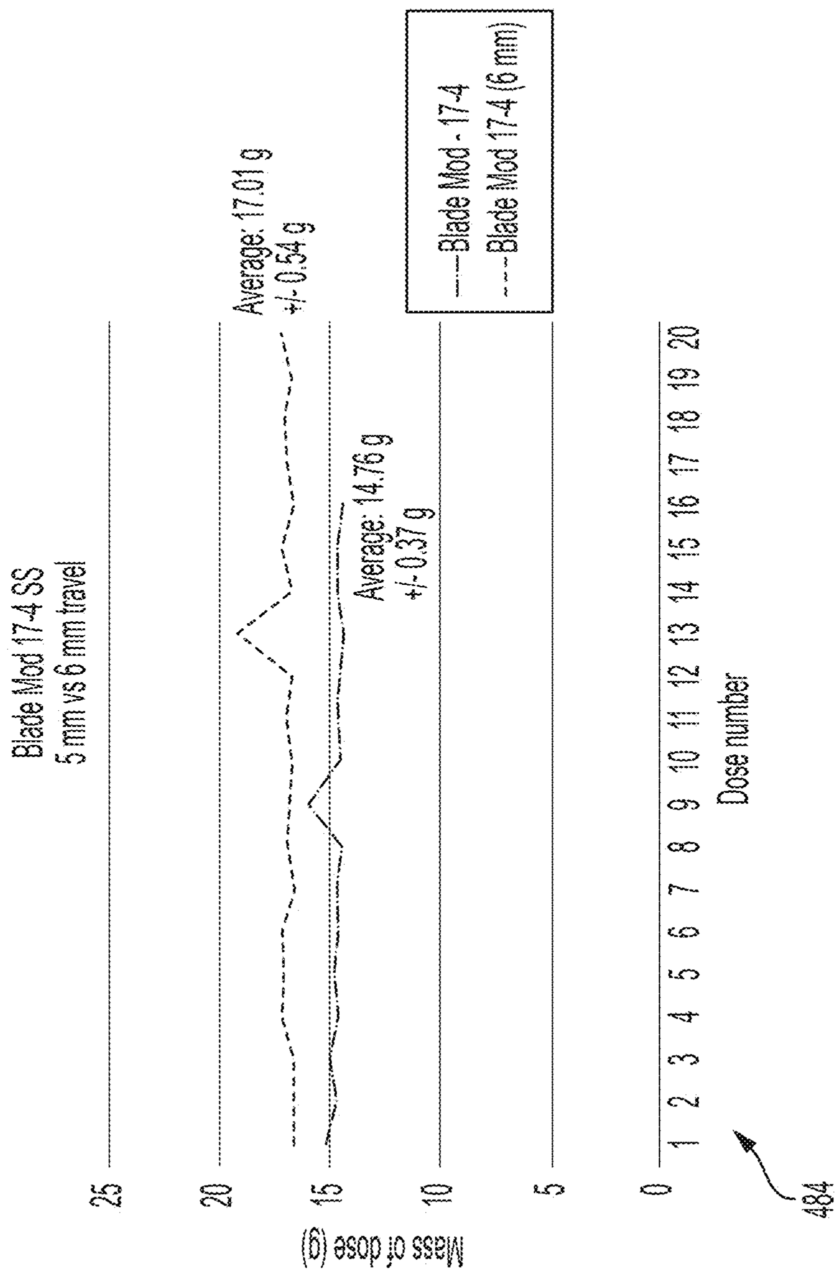


FIG. 4G-1
CONTINUED

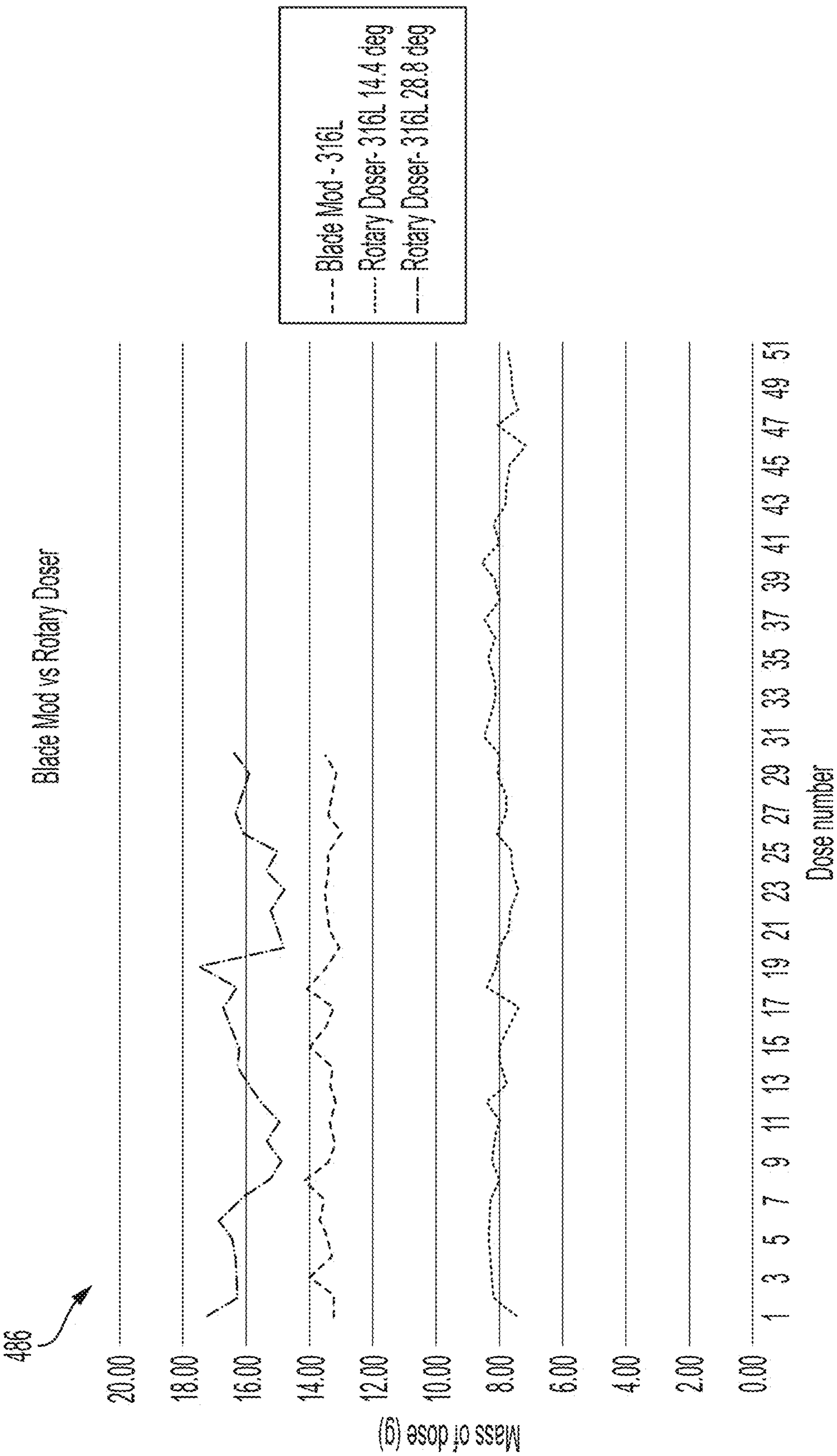

486
Blade Mod vs Rotary Doser
Blade Mod - 316L
Rotary Doser- 316L 14.4 deg
Rotary Doser- 316L 28.8 deg
Mass of dose (g)
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51
Dose number

FIG. 4G-2

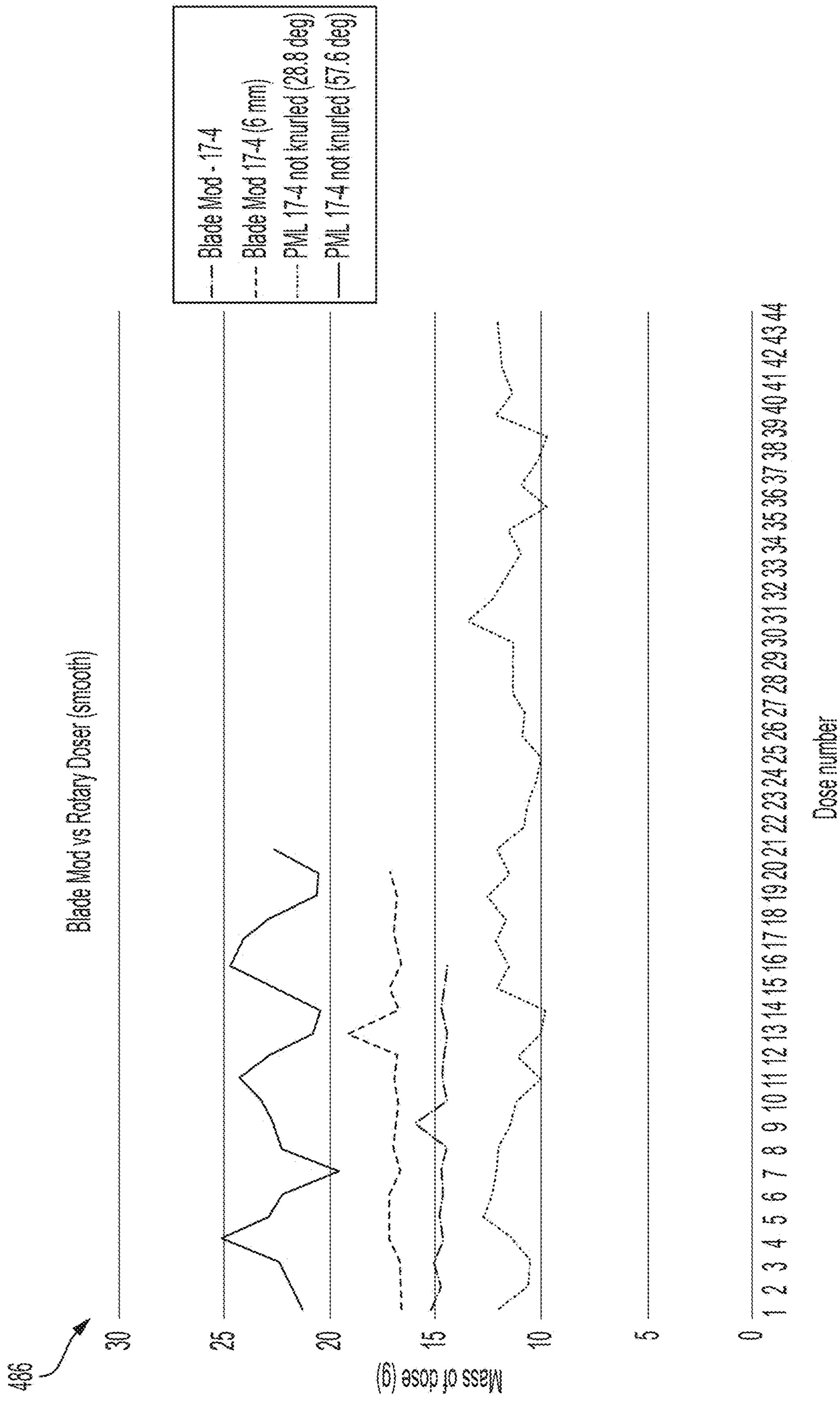


FIG. 4G-2
CONTINUED

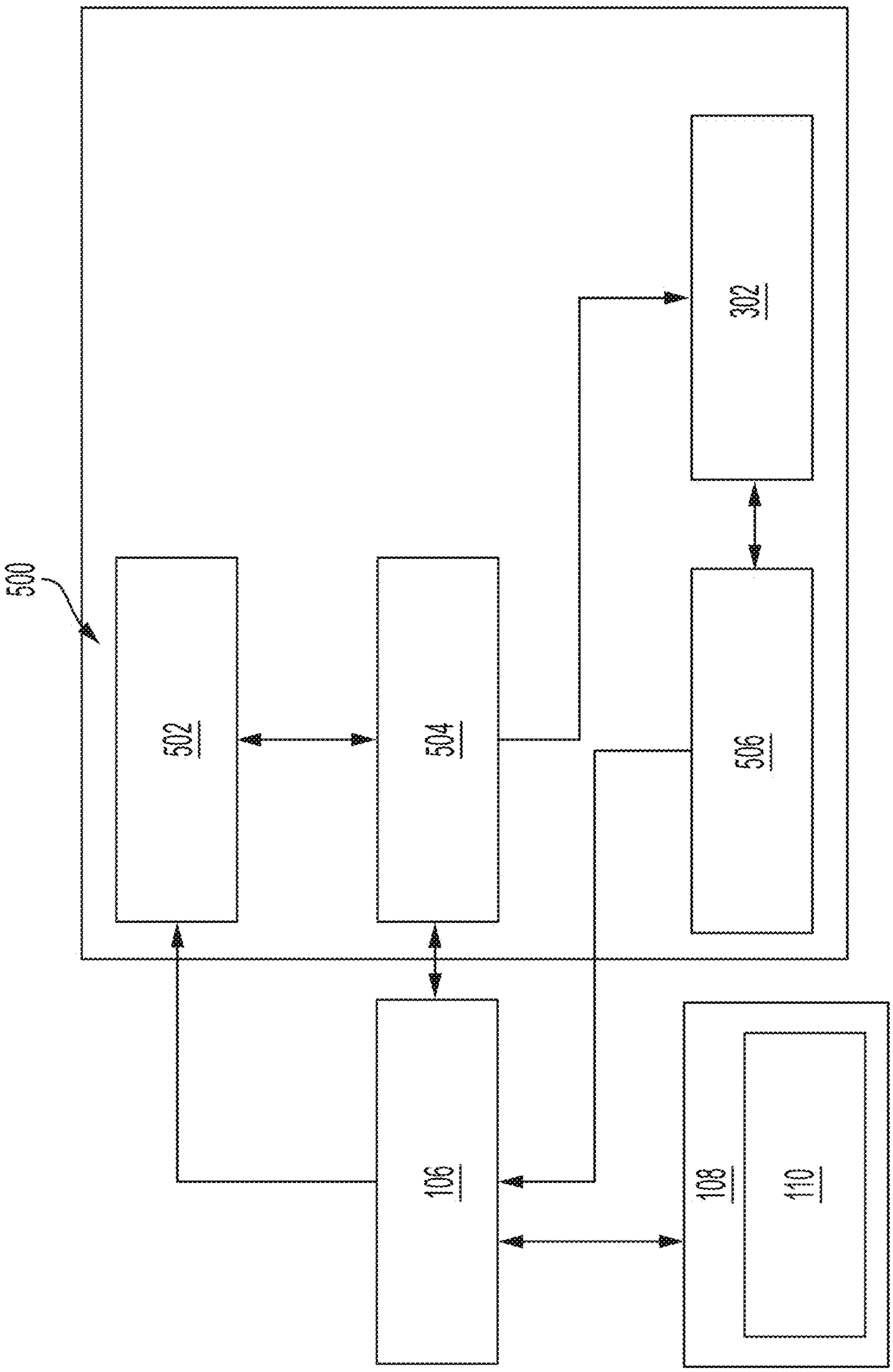


FIG. 5A

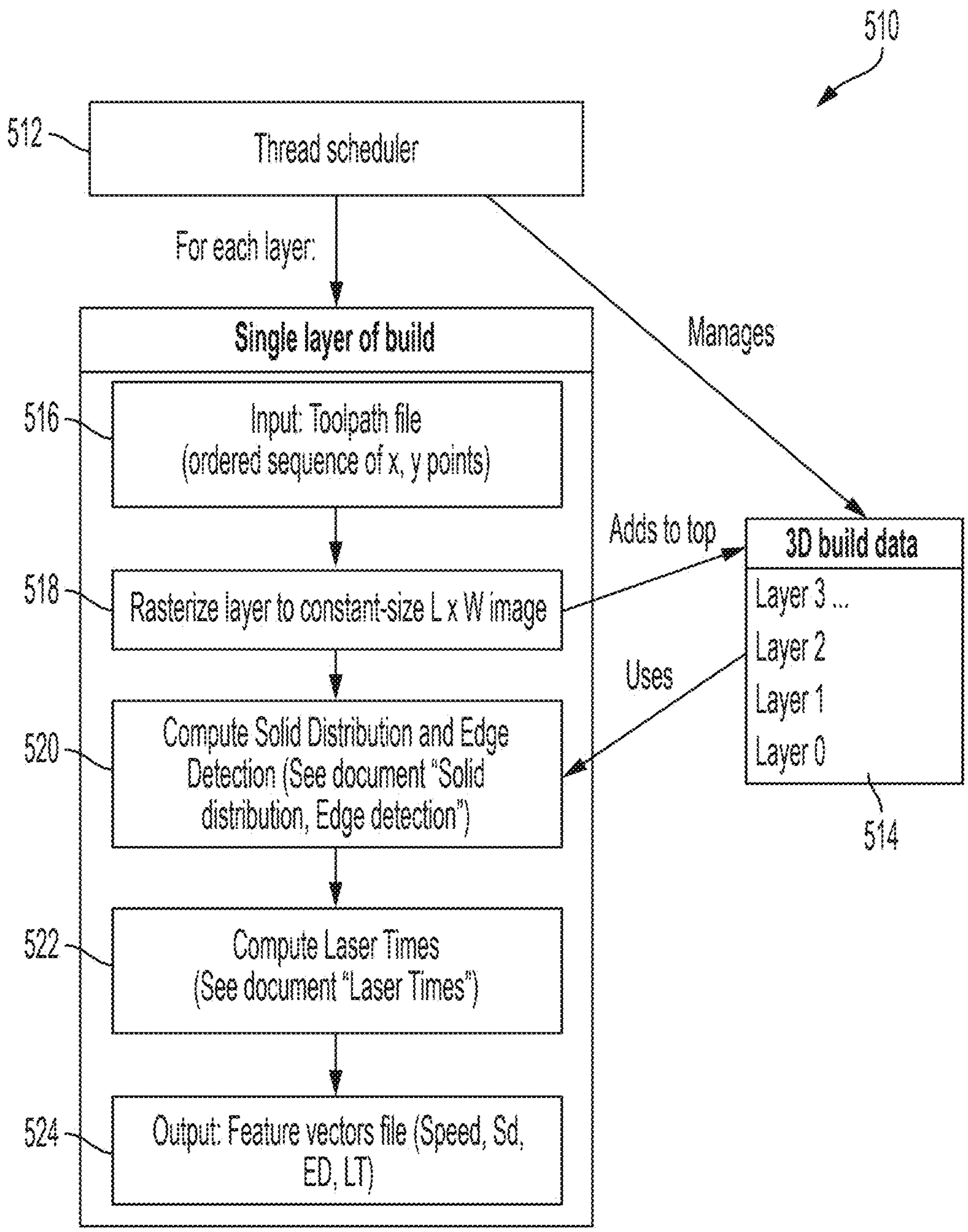

510
512
Thread scheduler
For each layer:
Manages
Single layer of build
516
Input: Toolpath file
(ordered sequence of x, y points)
518
Rasterize layer to constant-size L x W image
Adds to top
3D build data
Layer 3 ...
Layer 2
Layer 1
Layer 0
514
Uses
520
Compute Solid Distribution and Edge Detection (See document "Solid distribution, Edge detection")
522
Compute Laser Times
(See document "Laser Times")
524
Output: Feature vectors file (Speed, Sd, ED, LT)

FIG. 5B

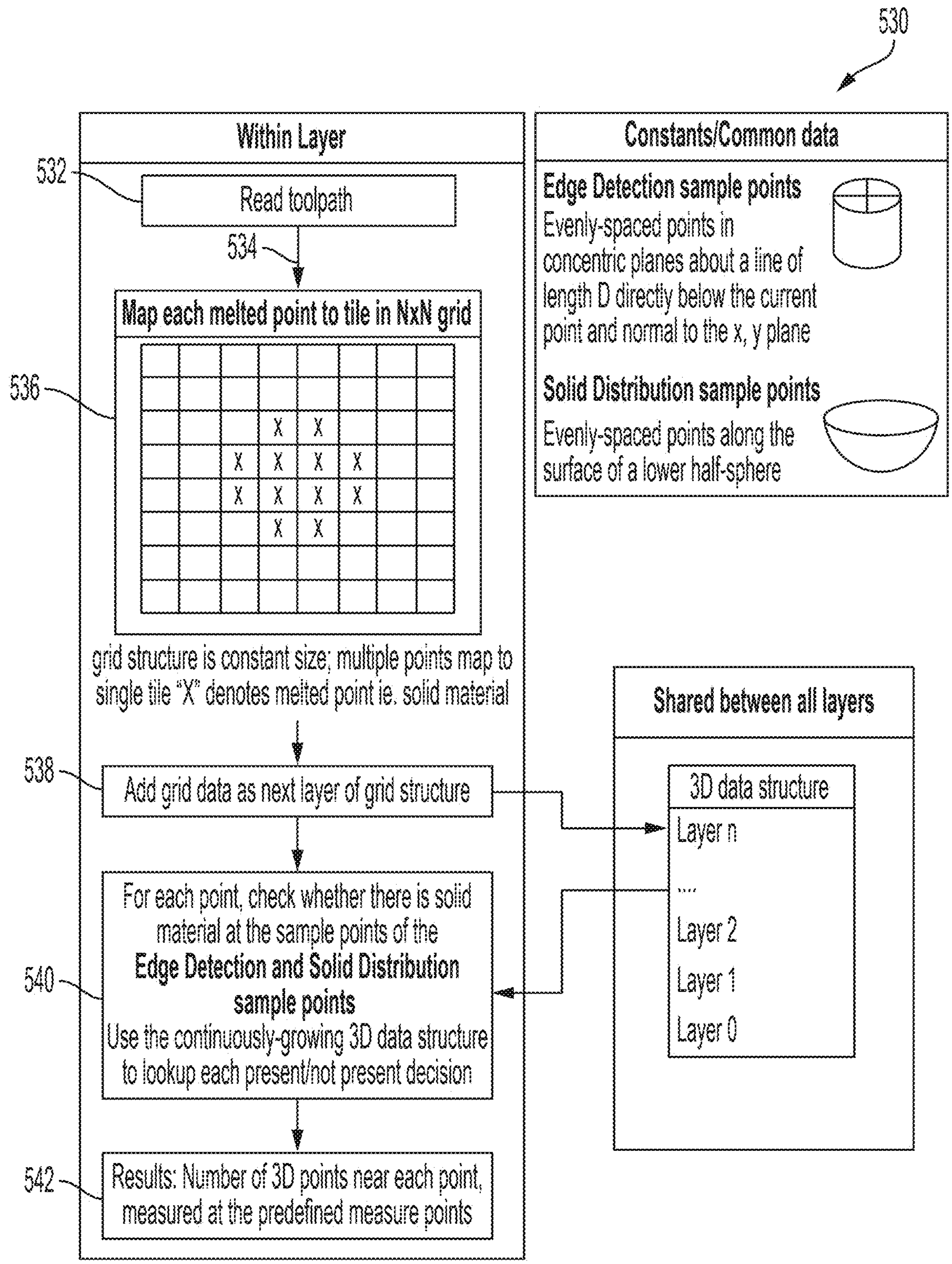

530
Within Layer
532
Read toolpath
534
Map each melted point to tile in NxN grid
536
X X
X X X X
X X X X
X X
grid structure is constant size; multiple points map to single tile "X" denotes melted point ie. solid material
538
Add grid data as next layer of grid structure
540
For each point, check whether there is solid material at the sample points of the
Edge Detection and Solid Distribution sample points
Use the continuously-growing 3D data structure to lookup each present/not present decision
542
Results: Number of 3D points near each point, measured at the predefined measure points
Constants/Common data
Edge Detection sample points
Evenly-spaced points in concentric planes about a line of length D directly below the current point and normal to the x, y plane
Solid Distribution sample points
Evenly-spaced points along the surface of a lower half-sphere
Shared between all layers
3D data structure
Layer n
....
Layer 2
Layer 1
Layer 0

FIG. 5C

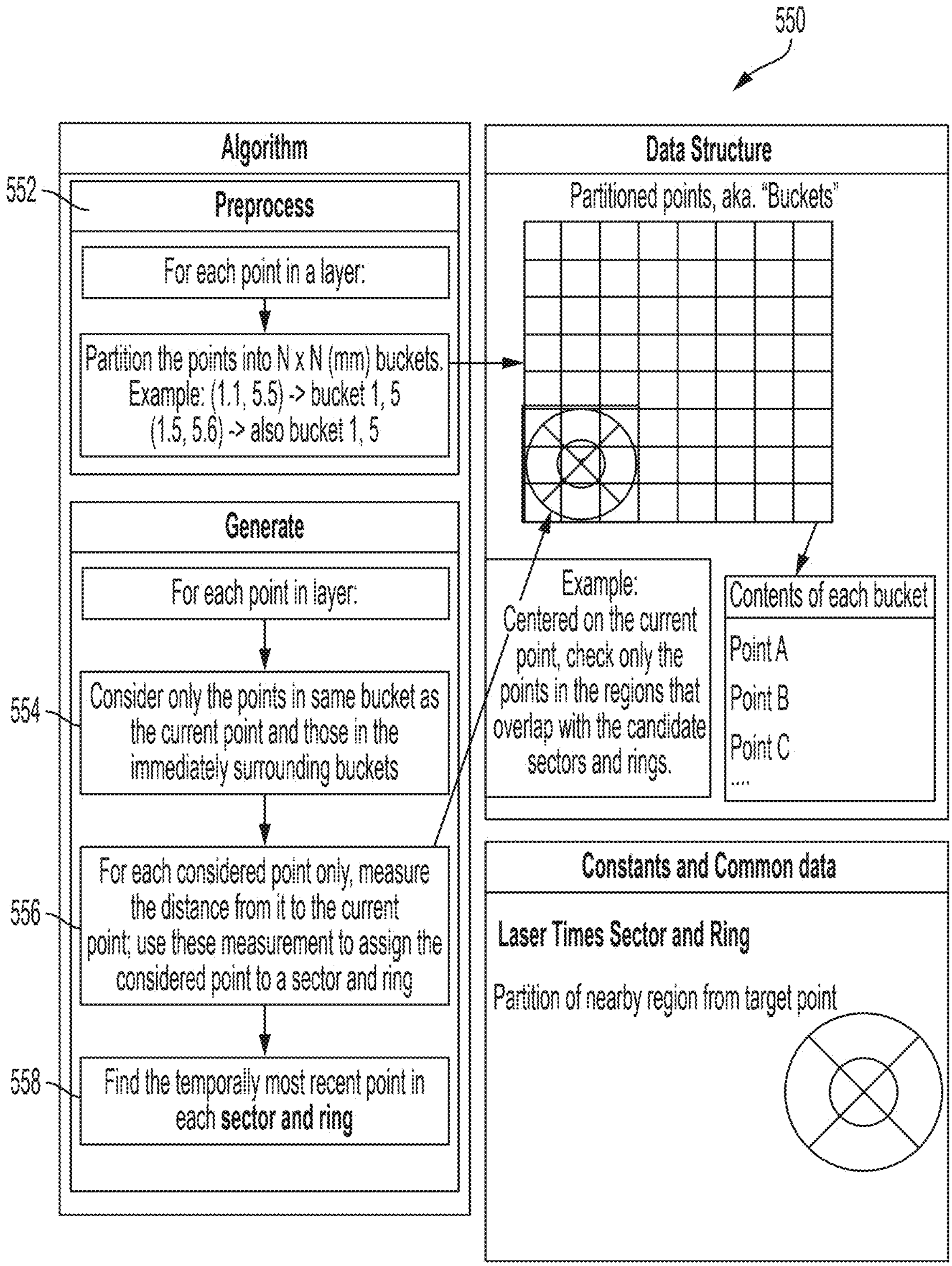

550
Algorithm
552
Preprocess
For each point in a layer:
Partition the points into N x N (mm) buckets.
Example: (1.1, 5.5) -> bucket 1, 5
(1.5, 5.6) -> also bucket 1, 5
Generate
For each point in layer:
554
Consider only the points in same bucket as the current point and those in the immediately surrounding buckets
556
For each considered point only, measure the distance from it to the current point; use these measurement to assign the considered point to a sector and ring
558
Find the temporally most recent point in each sector and ring
Data Structure
Partitioned points, aka. "Buckets"
Example:
Centered on the current point, check only the points in the regions that overlap with the candidate sectors and rings.
Contents of each bucket
Point A
Point B
Point C
....
Constants and Common data
Laser Times Sector and Ring
Partition of nearby region from target point

FIG. 5D

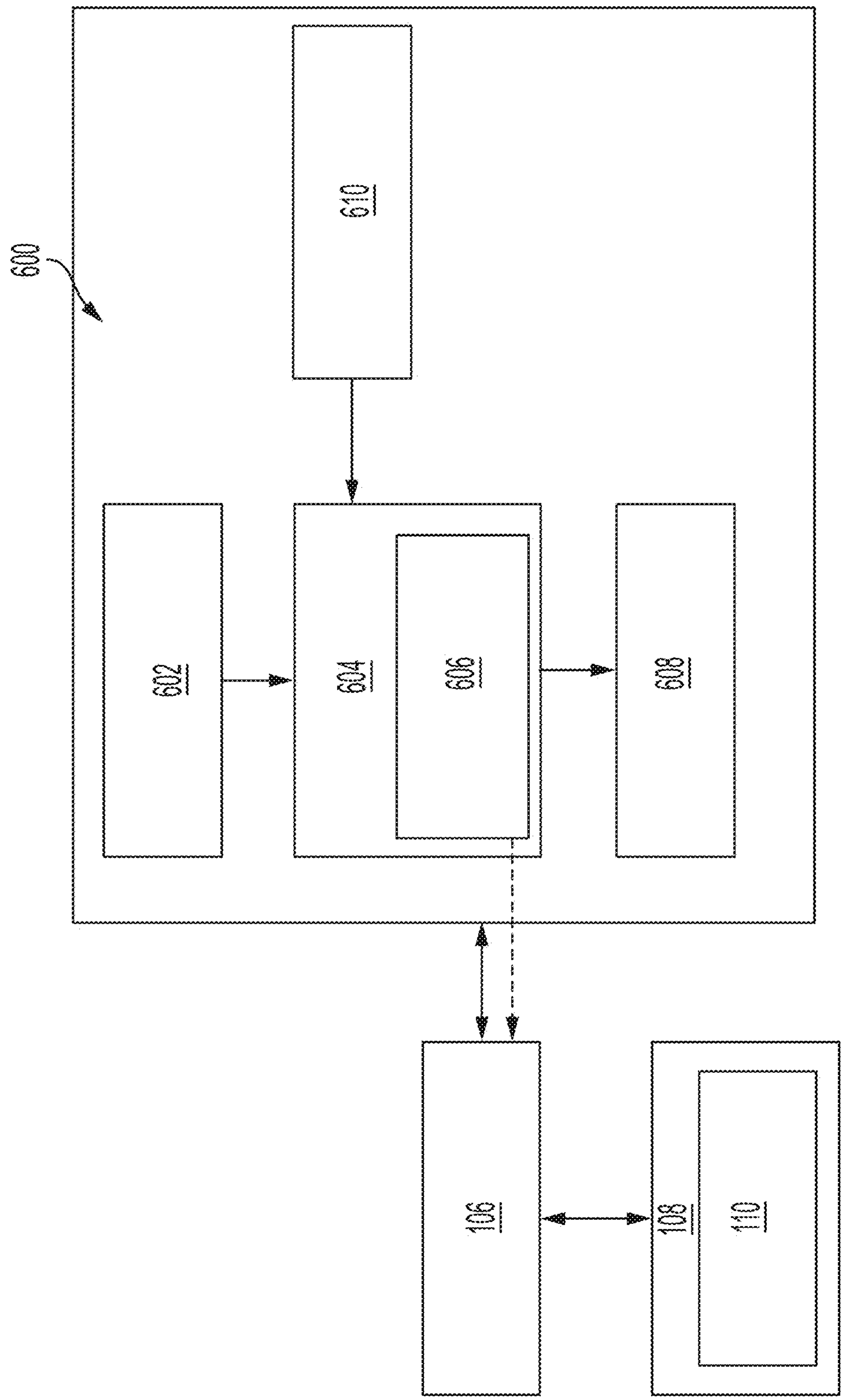


FIG. 6A

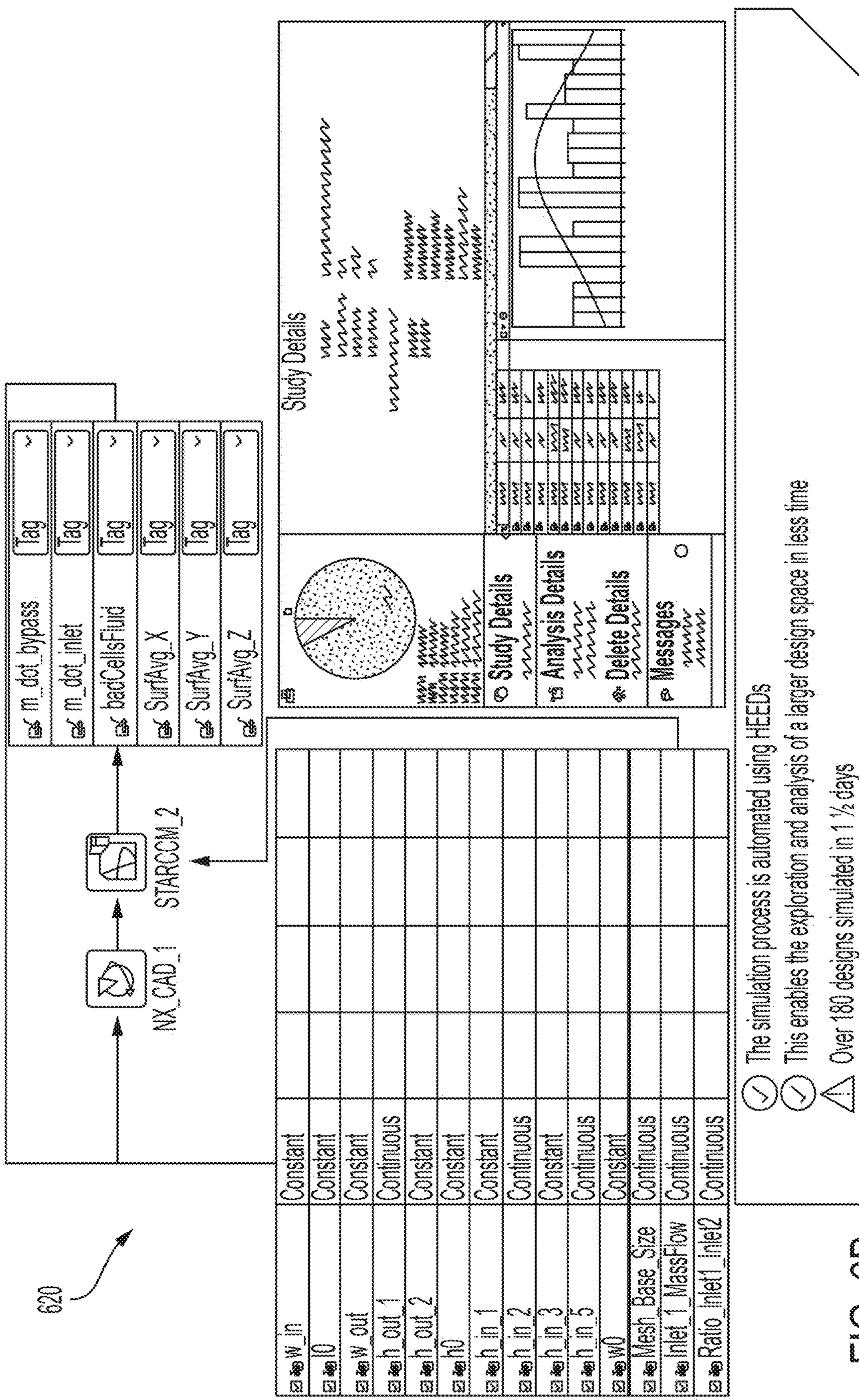

620
NX_CAD_1
STARCOM_2
m_dot_bypass
m_dot_inlet
badCellsFluid
SurfAvg_X
SurfAvg_Y
SurfAvg_Z
Tag
w_in Constant
l0 Constant
w_out Constant
h_out_1 Continuous
h_out_2 Constant
h0 Constant
h_in_1 Constant
h_in_2 Continuous
h_in_3 Constant
h_in_5 Continuous
w0 Constant
Mesh_Base_Size Continuous
Inlet_1_MassFlow Continuous
Ratio_Inlet1_Inlet2 Continuous
Study Details
Analysis Details
Delete Details
Messages
The simulation process is automated using HEEDs
This enables the exploration and analysis of a larger design space in less time
Over 180 designs simulated in 1 ½ days

FIG. 6B

Front view

Constraint	Min Value	Max Value	Location	Unit
Volumetric Flowrate	X	X X	-	lpm
Minimum Velocity within main wall jet	X	X	X/X	m/s
Inlet Jet Height	X	Inf.		mm
Uniformity Index h1 (xy-plane)	X		X (X x X sq)	mm
Uniformity Index h2 (xy-plane)	X		X (X x X sq)	mm
Uniformity Index h3 (xy-plane)	X		X (X x X sq)	mm
Vortex/Recirculation	- inf	X	X	mm
Outlet Velocity Limit	X	X	-	m/s
		-	-	
		-	-	

622

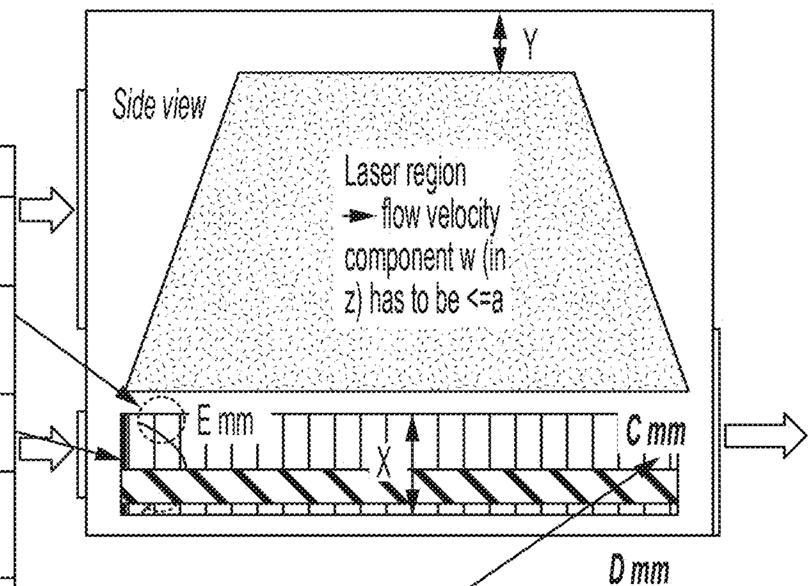


FIG. 6C

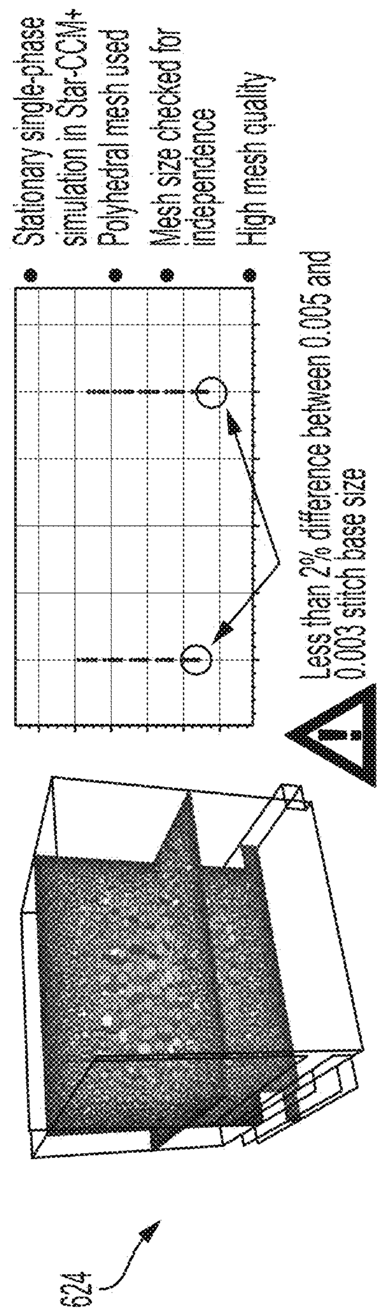

624
Stationary single-phase simulation in Star-CCM+
Polyhedral mesh used
Mesh size checked for independence
High mesh quality
Less than 2% difference between 0.005 and 0.003 stitch base size

FIG. 6D

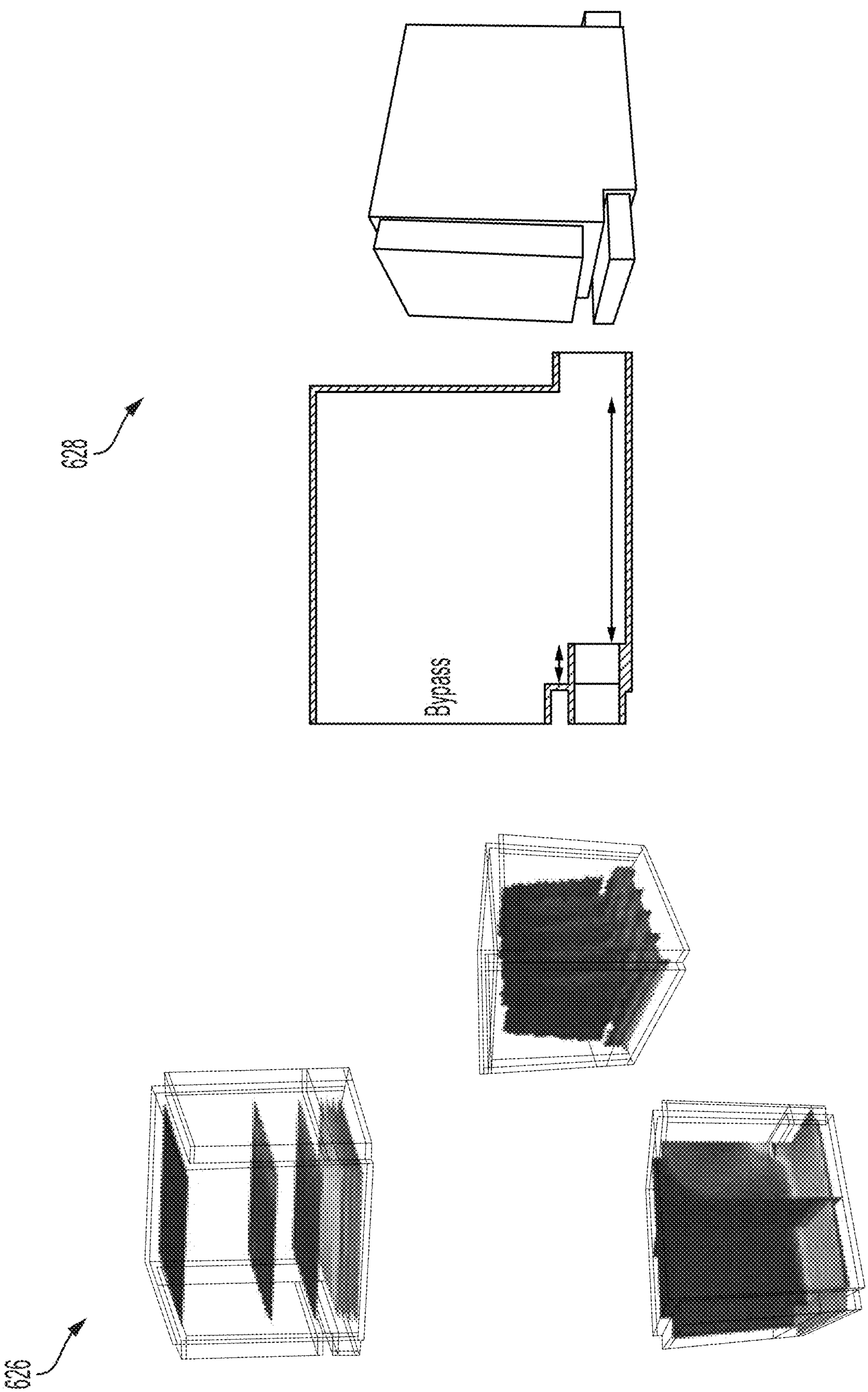


FIG. 6E

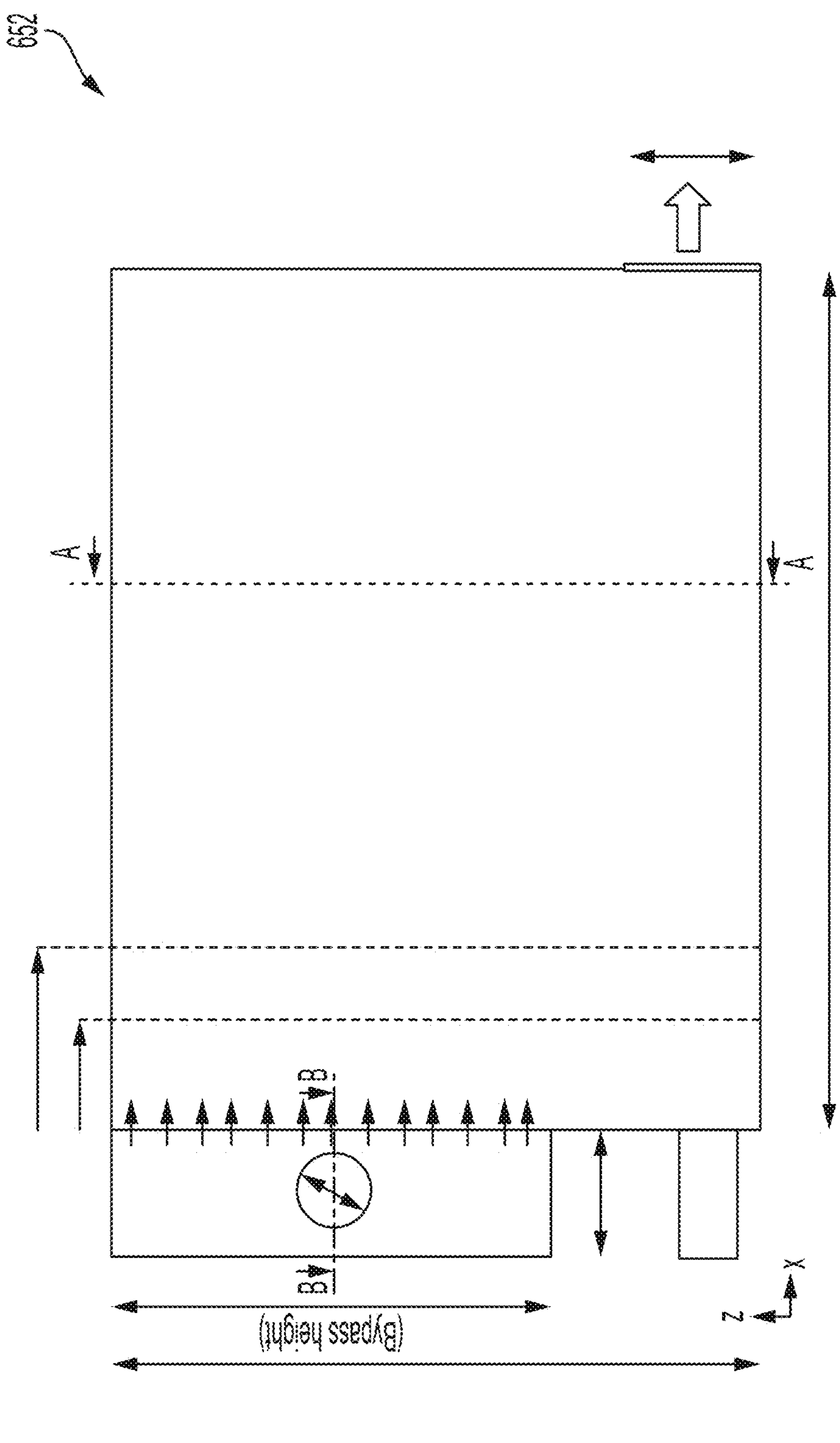


FIG. 6F-1

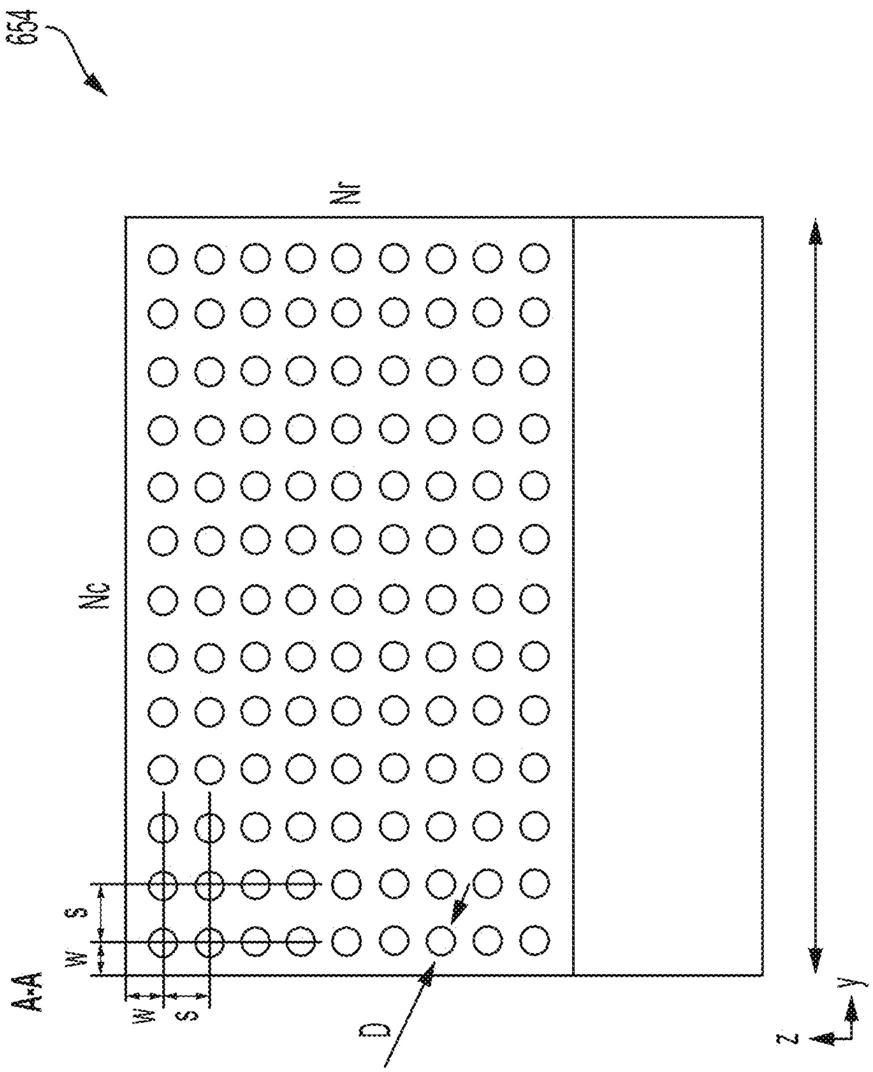


FIG. 6F-2

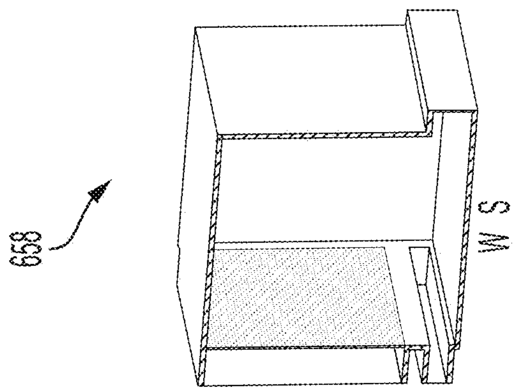


FIG. 6F-4

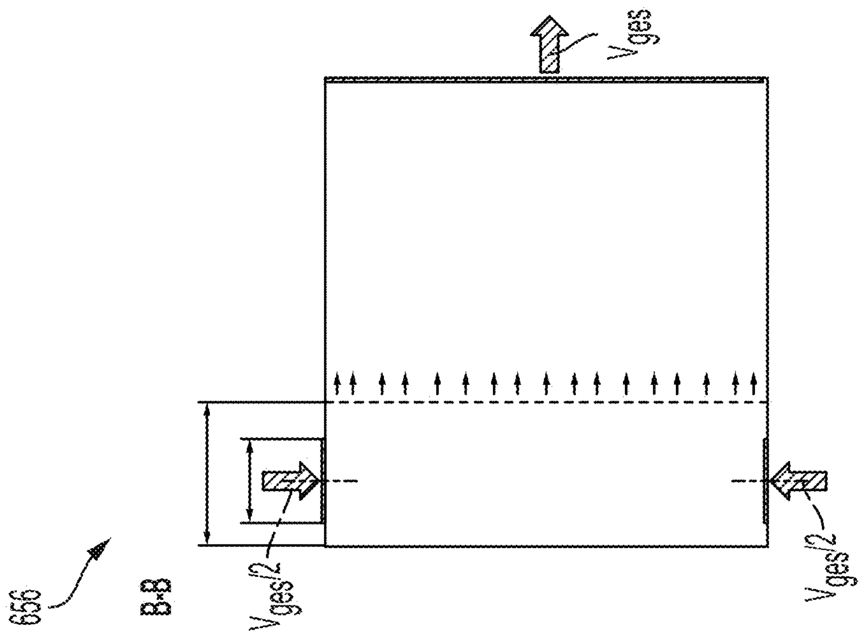


FIG. 6F-3

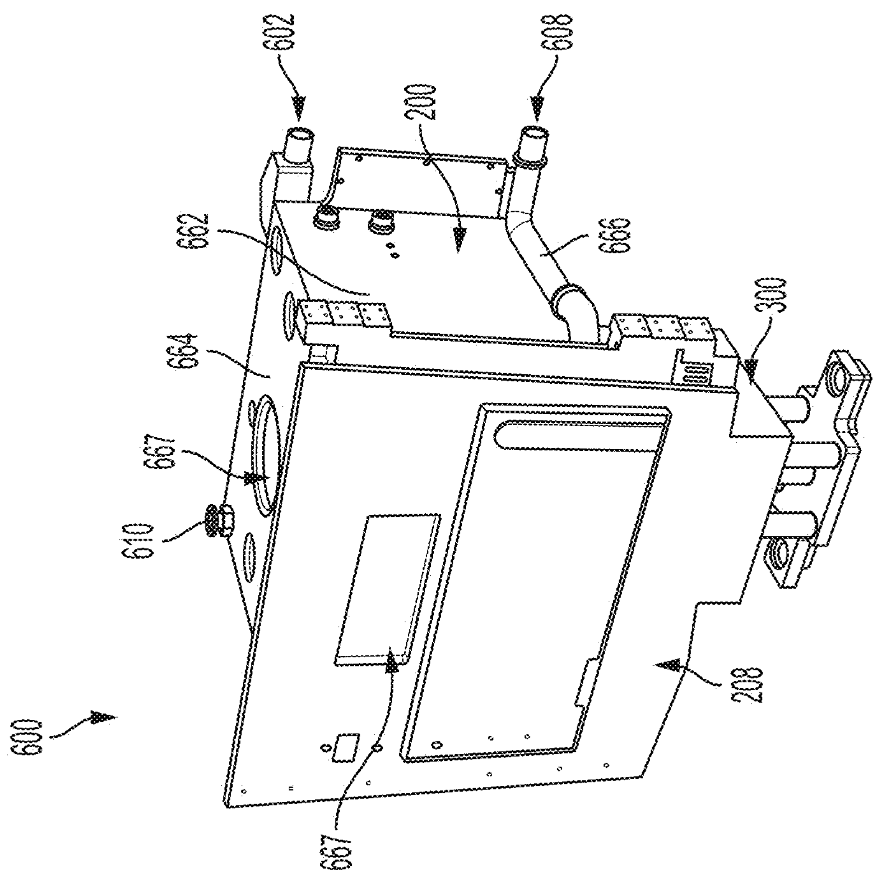


FIG. 6G-1

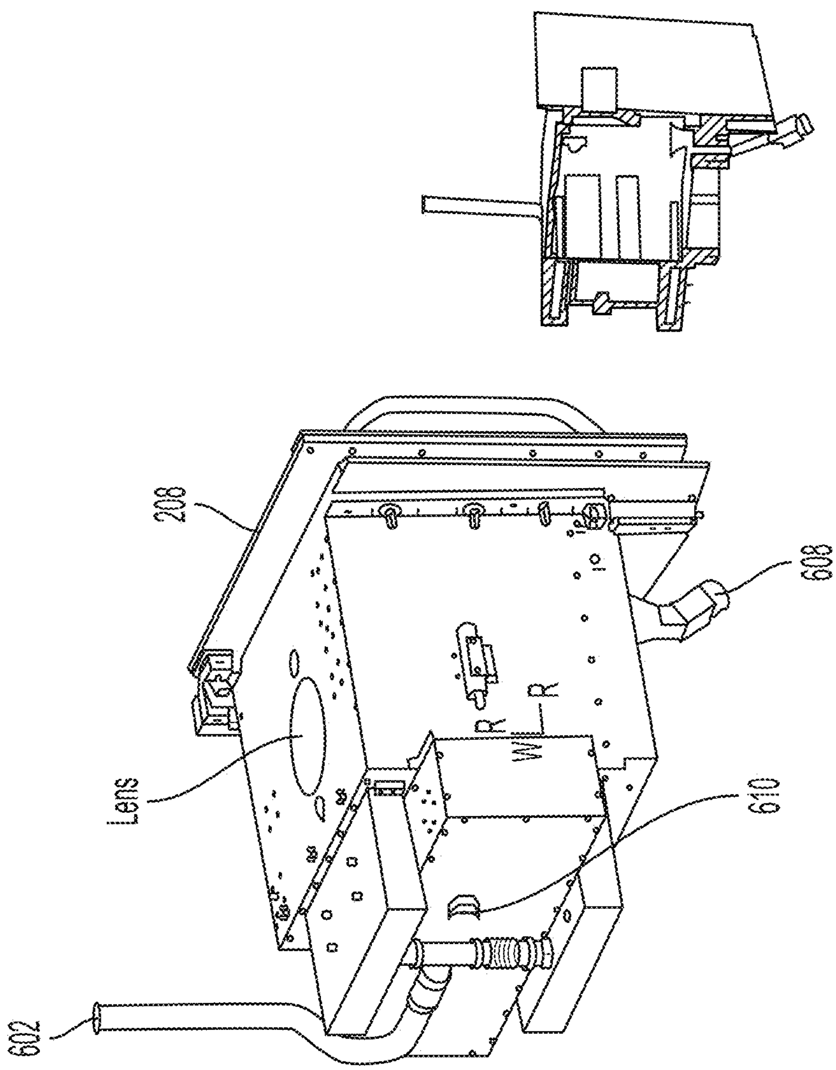


FIG. 6G-2

668

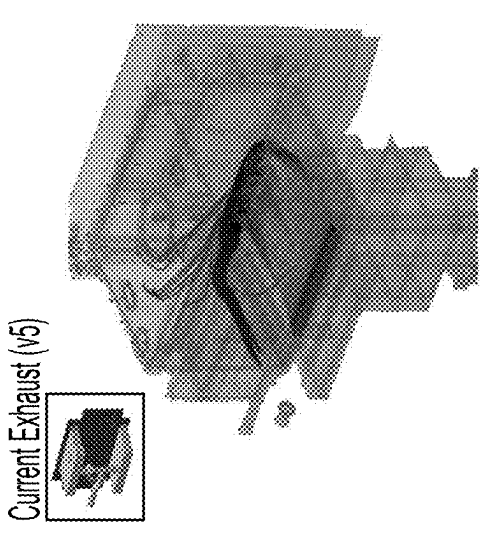


FIG. 6H-1

670

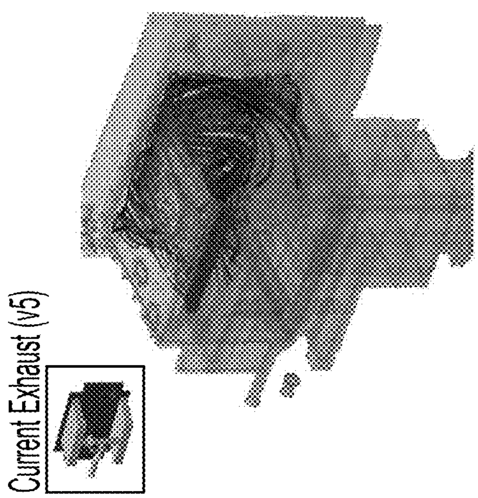


FIG. 6H-2

672

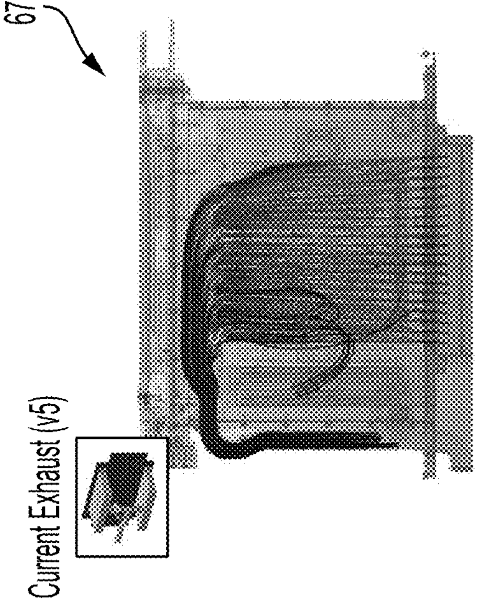


FIG. 6H-3

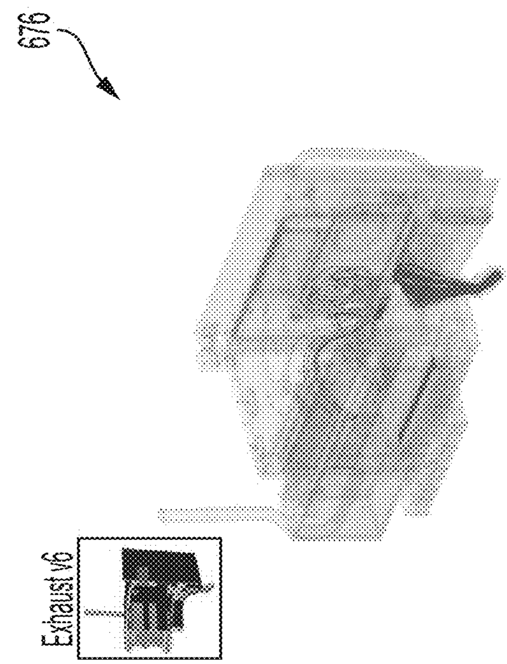


FIG. 6I-2

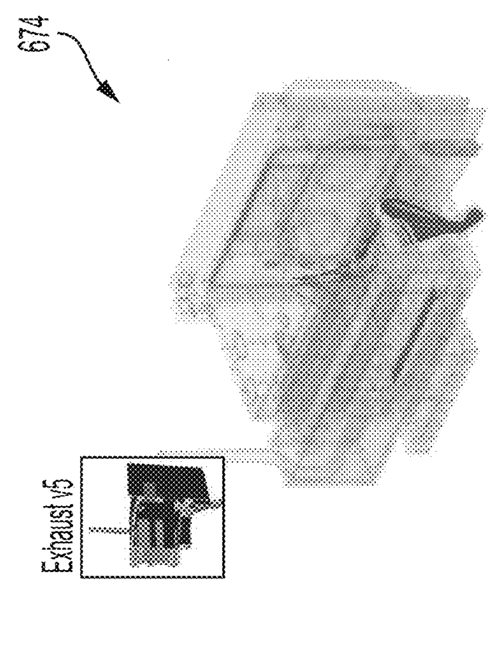


FIG. 6I-1

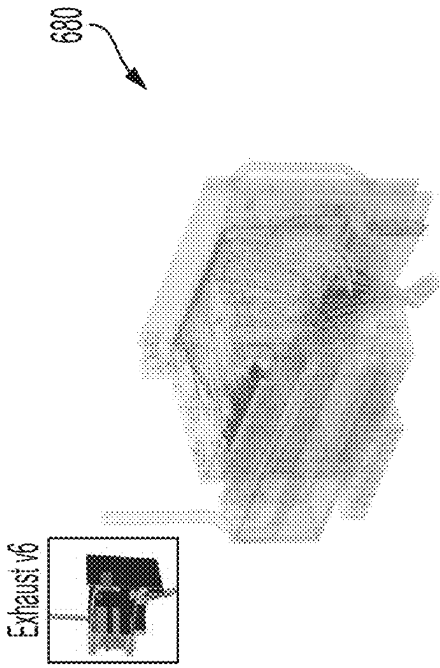


FIG. 6I-4

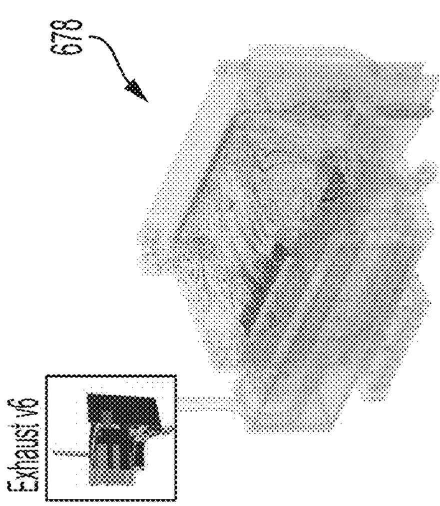


FIG. 6I-3

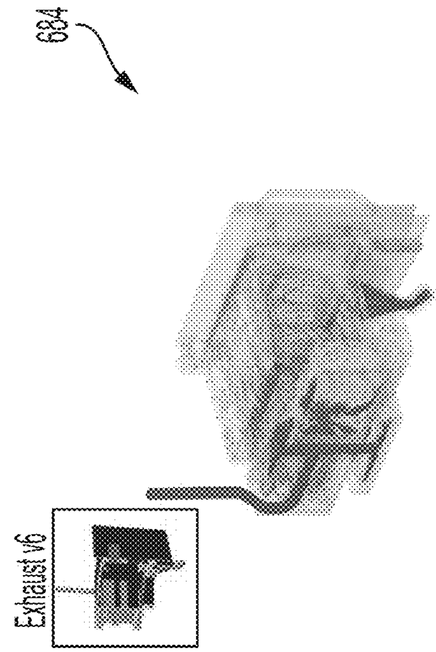


FIG. 6I-6

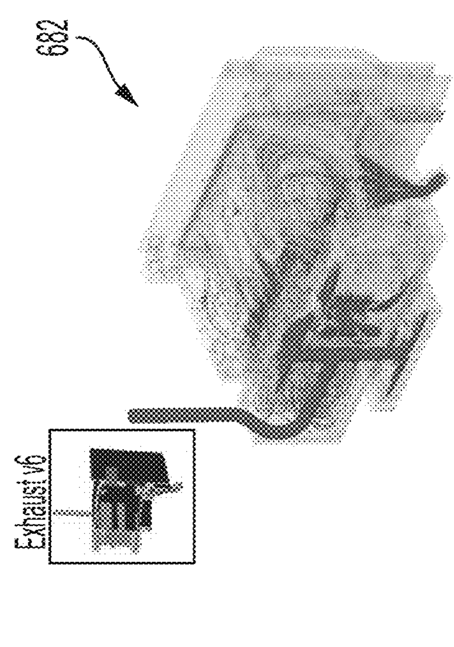


FIG. 6I-5

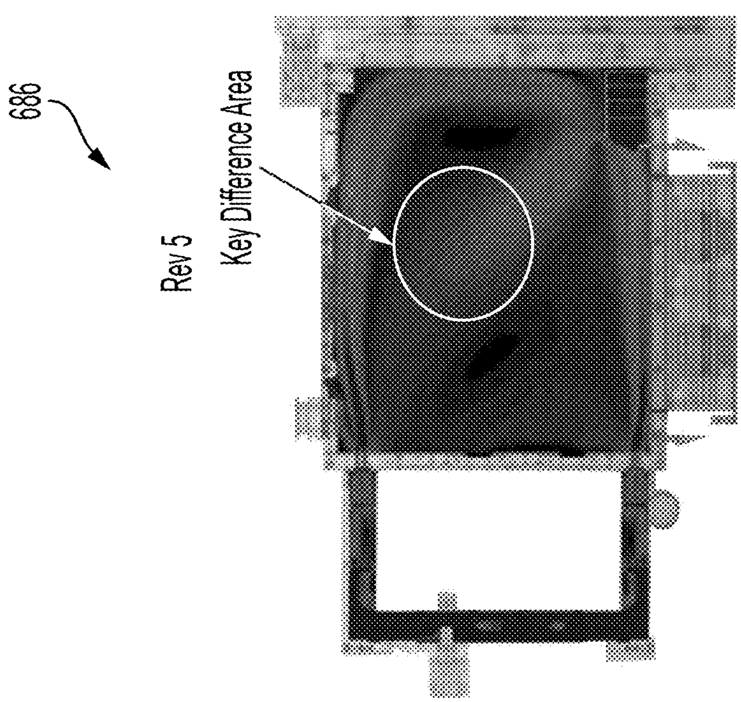


FIG. 6J-1

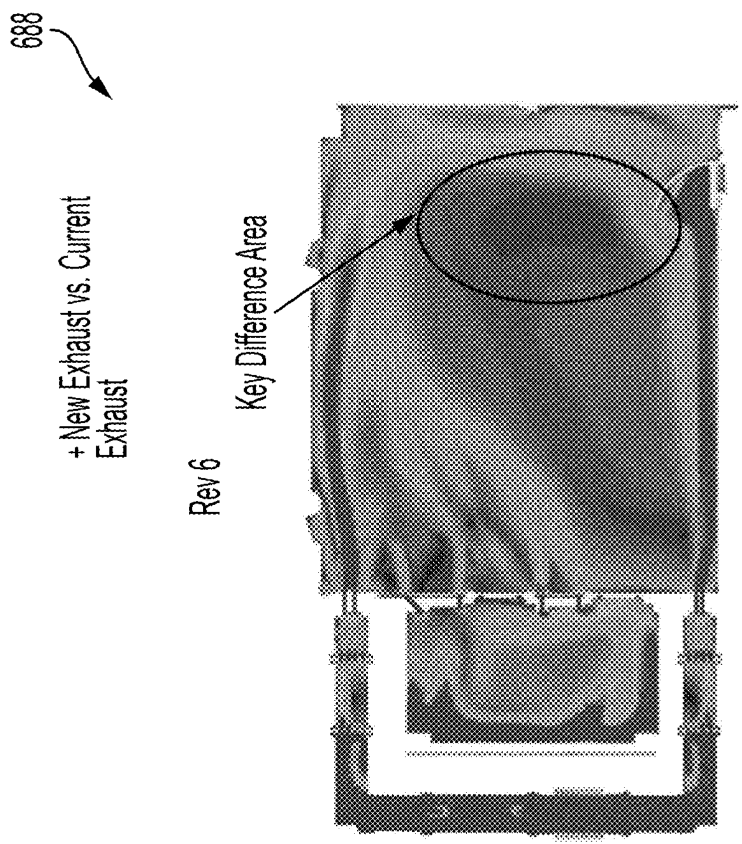


FIG. 6J-2

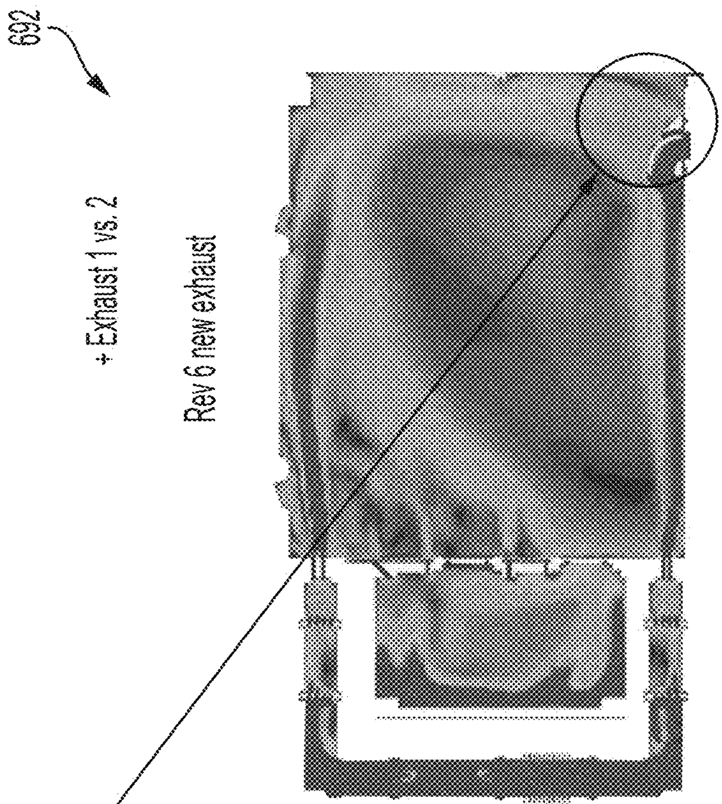


FIG. 6J-4

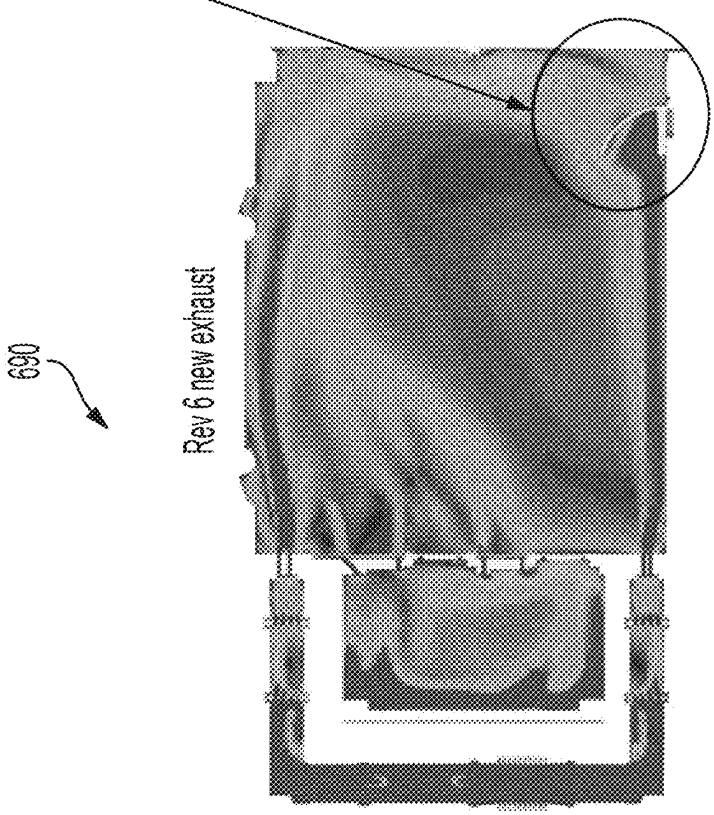


FIG. 6J-3

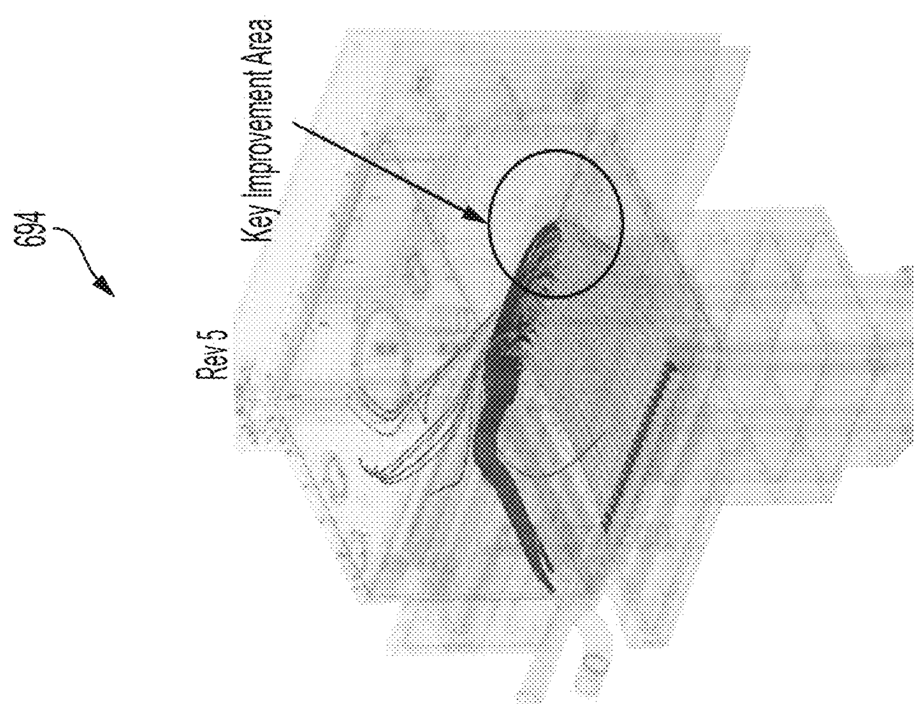


FIG. 6J-5

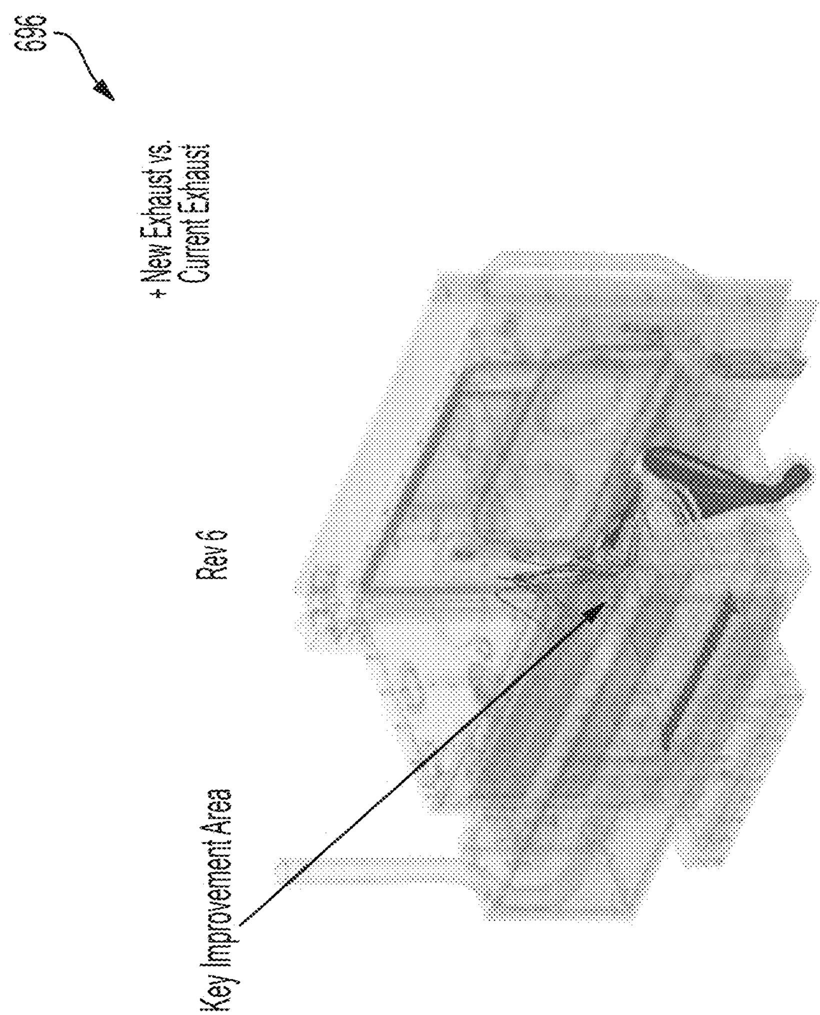


FIG. 6J-6

ADDITIVE MANUFACTURING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit of U.S. Patent Application No. 63/561,711, entitled "ADDITIVE MANUFACTURING SYSTEM" filed on 5 Mar. 2024, U.S. Patent Application No. 63/561,526, entitled "Z-AXIS LEVELING" filed on 5 Mar. 2024, U.S. Patent Application No. 63/561,549, entitled "ADAPTIVE BEAM CONTROL" filed on 5 Mar. 2024, U.S. Patent Application No. 63/561,580, entitled "DYNAMIC GAS FLOW SYSTEM FOR ADDITIVE MANUFACTURING" filed on 5 Mar. 2024, and U.S. Patent Application No. 63/561,714, entitled "POWDER DELIVERY SYSTEM" filed on 5 Mar. 2024, which are incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present disclosure generally relates to additive manufacturing, and more particularly, a system able to layer-wise construct a three-dimensional object by means of additive manufacturing.

BACKGROUND

[0003] Traditionally, materials are processed into desired shapes and assemblies through a combination of rough fabrication techniques (e.g., casting, rolling, forging, extrusion, and stamping) and finish fabrication techniques (e.g., machining, welding, soldering, polishing). Producing a complex assembly in final, usable form ("net shape"), which often may require not only forming the part with the desired materials in the proper shapes but also providing the part with the desired combination of metallurgical properties (e.g., various heat treatments, work hardening, complex microstructure), typically requires considerable investment in time, tools, and effort.

[0004] One or more of the rough and finish processes may be performed using manufacturing centers, such as Computer Numerically Controlled (CNC) machine tools. CNC machine tools use precisely programmed commands to automate the manufacturing process. The commands may be generated using computer-aided design (CAD) and/or computer-aided manufacturing (CAM) programs. Examples of CNC machines include, but are not limited to, mills, lathes, mill-turns, plasma cutters, electric discharge machines (EDM), and water jet cutters. CNC machining centers have been developed which provide a single machine having multiple tool types that is capable of performing multiple different machining processes. Such machining centers may generally include one or more tool retainers, such as spindle retainers and turret retainers holding one or more tools, and a workpiece retainer, such as a pair of chucks. The workpiece retainer may be stationary or move (in translation and/or rotation) while a tool is brought into contact with the workpiece, thereby performing a subtractive manufacturing process during which material is removed from the workpiece.

[0005] Because of cost, expense, complexity, and other factors, additive manufacturing techniques have been developed that enable a new range of engineering freedom that was otherwise limited. Components with internally unreachable features can be produced and costs are similar despite ranges of complexity. In contrast to subtractive manufacturing processes, which focus on precise removal of material from a workpiece, additive manufacturing processes add material, typically in a computer-controlled environment, by creating successive layers of material to form a three-dimensional object. Additive manufacturing techniques may improve efficiency and reduce waste while expanding manufacturing capabilities, such as by permitting seamless construction of complex configurations which, when using conventional manufacturing techniques, would have to be assembled from a plurality of component parts. The opportunity for additive techniques to enable a new range of manufacturing depends on several factors, such as the range of materials available for use in the additive processes, the size and surface finish that can be achieved using additive techniques, and the rate at which material can be added. Additive processes may advantageously be capable of fabricating complex precision net-shape components ready for use. In some cases, however, the additive process may generate "near-net shape" products that require some degree of finishing. Additive manufacturing techniques include, but are not limited to, powder bed fusion processes such as laser sintering, laser melting, and electron beam melting.

[0006] Prior to building the work piece, the build platform should be level. Ensuring the build platform is level is crucial because it is the foundation of each layer on top of it that becomes the completed work piece. Additive manufacturing machines may require leveling before each build or at least regular leveling due to environmental factors (e.g., frequent usage, high traffic areas and/or vibrations from other machinery). Small initial deviations from a level state on the build platform can be magnified and will propagate vertically as each successive layer is built on top of the build platform.

[0007] Conventional build platform leveling systems may use mechanical leveling techniques that require high amounts of user interaction or skill and multiple iterations to attempt to achieve a level state of the build platform. Such conventional build platform leveling systems may use multiple screws or posts that each need to be rotated to adjust their height to achieve a level state of the build platform. For example, conventional leveling processes involved installing a plate on the base, measuring the four corners of the plate, taking the plate out to make adjustments to its height, placing the plate back on the base, measuring again to check levelness, and repeating the process for 30-60 minutes to reach a level state. Achieving a level state with these types of systems is highly dependent on the skill of the user. Build plates are heavy and make removing and/or adjusting them difficult.

[0008] Powder delivery systems for additive manufacturing processes typically include many components working together in series to deliver powder to the build chamber, such as augers, rollers, and linkages to move and spread metal powder from a tank adjacent to the build chamber. Previous powder delivery systems could be sources of problems because they rely on many components working in series, and the failure of one component leads to the failure of the powder delivery system as a whole. The reliability of a system using multiple parts in series is the product of the reliability of the subsystems. As the number of subsystems grows, the reliability of every subsystems must be ensured to prevent the failure of the larger system. It is advantageous to make the number of subsystems no greater than it needs to be to complete the desired task.

[0009] Additive manufacturing processes uses an energy source for melting metal power, such energy sources can be a fiber laser with a common irradiation wavelength of 1070 nm although other wavelengths can be used as well as other energy sources such as electron beams. When the irradiating beam interacts with metal powders in the process it creates particle ejecta, smoke, fumes, soot, and other impurities (collectively, "particulates"). These particulates may have different densities and properties. For instance, some particulates are agglomerated particles or denudated powder leaving the molten pool. Other particulates comprise soot which is less dense and more rapidly rises above the molten pool. In general, it can be said that the particulate has the potential and often circulates in eddies within the work chamber and where there is improper or insufficient flow. This recirculation can interfere with the laser's function of fusing the powder on the build platform to create layers of the work piece being built. Even small interference of the laser's function can have negative impacts on the work piece in a range of resultant qualities from surface finish to internal material properties.

[0010] Typical additive manufacturing gas flow systems include a single primary inlet and a possible secondary shielding inlet and generally a single outlet in the build chamber. Typical additive manufacturing processes use a static gas flow circuit such that the path of the gas flow is constant in the work chamber and would be considered steady-state when the gas pump is turned on after initial ramp-up. The gas flow circuit is given and set point target and holds that for the duration of the build regardless of geometry, material, or particulate load of melting. Utilizing the typical static gas flow is a contradiction to the inherently transient process of layer wise manufacturing. For example, the laser is actively traversing the build area in different locations, the geometry of the produced parts is dependent on the layer, and the recoater traverses the chamber in between every layer to supply additional raw material.

[0011] Additive manufacturing devices typically use constant energy input amount with fixed optics. This approach can introduce inconsistencies in deposition track morphology and material properties when the steady state is disturbed, such as the size of the feature affecting heat accumulation, resulting in temperature and cooling rates outside the desired ranges.

[0012] The large temperature fluctuations caused by the point-by-point melting of a powdered material can create thermal stresses within the printed object. Furthermore, material properties, such as the grain size of the melted material may vary due to variations in the thermal history at different locations in the finished part. For example, the increase in temperature may cause localized regions of the melted portion to recrystallize and form a region that has a different grain size from a neighboring region.

[0013] The laser powder bed fusion (LPBF) process is susceptible to build imperfections across different regions of a given part being created due to dynamic process conditions such as residual heat in the part after interaction with the laser, as well as specific part geometries such as thin walls and overhangs. Control of the energy distribution on the surface of the part to ensure a consistent melt pool is essential. The current standard of applying static process parameters at a macro level (such as for parts and general geometries) can be improved upon.

[0014] In the past, laser parameters, such as laser power, speed, profile (spot size), and location, for the LPBF process were static. The static parameters were determined pre-build and only accounted for macro-level geometries of the part to be built. Utilizing static laser parameters results in poor build quality in some parts and/or in some regions of parts due to dynamic process conditions that occur during the build and geometries of the part, such as excess residual heat in regions.

SUMMARY

[0015] Disclosed herein are approaches for addressing various of the problems and shortcomings of the state of the art, as identified above. More particularly, disclosed herein is a system able to layer-wise construct a three-dimensional object by means of additive manufacturing.

[0016] According to a first aspect of the present disclosure, there is provided an additive manufacturing system for manufacturing a component, the additive manufacturing system comprising a frame, an additive manufacturing machine disposed on the frame, a processor electronically coupled to the additive manufacturing machine, and a memory unit comprising stored instructions for controlling the additive manufacturing machine. The additive manufacturing machine includes a Z-axis levelling system comprising a build platform for manufacturing the component and configured for adjusting a height of the build platform, a build chamber configured to accommodate the build platform, a powder delivery system configured to deliver the material powder to the build platform, an adaptive laser beam control system disposed inside the build chamber and comprising at least one laser for irradiating the material powder on the build platform, and a dynamic gas flow system disposed on the build chamber configured to deliver and regulate a flow of gas in and out of the build chamber and remove, from the build chamber, particulates created during the irradiation of the material powder by the at least one laser.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. **1** shows a schematic of an exemplary aspect of an additive manufacturing system.

[0018] FIG. **2**A shows a schematic top view of an exemplary embodiment of a build chamber according to an aspect of the additive manufacturing system.

[0019] FIG. **2**B shows a perspective view of an exemplary embodiment of a build chamber according to an aspect of the additive manufacturing system.

[0020] FIG. **3**A shows a schematic of an exemplary embodiment of a Z-axis leveling system according to an aspect of the additive manufacturing system.

[0021] FIG. **3**B shows a perspective view of an exemplary embodiment of a Z-axis leveling system according to an aspect of the additive manufacturing system.

[0022] FIG. **3**C shows a perspective view of an exemplary embodiment of a Z-axis leveling system according to an aspect of the additive manufacturing system.

[0023] FIG. **3**D-**1** shows a perspective view of an exemplary embodiment of a build platform, a base, and a base platform according to an aspect of the additive manufacturing system.

[0024] FIG. **3**D-**2** shows a side view of an exemplary embodiment of a leveling cone according to an aspect of the additive manufacturing system.

[0025] FIG. **3**D-**3** shows a top view of an exemplary embodiment of a leveling cone according to an aspect of the additive manufacturing system.

[0026] FIG. **3**D-**4** shows a perspective view of the lower side of an exemplary embodiment of the build platform according to an aspect of the additive manufacturing system.

[0027] FIG. **3**E shows a perspective view of an exemplary embodiment of a height adjuster according to an aspect of the additive manufacturing system.

[0028] FIG. **3**F shows a perspective view of an exemplary embodiment of a vertical actuator with vertical guides according to an aspect of the additive manufacturing system.

[0029] FIG. **3**G shows a perspective view of an exemplary embodiment of a leveling system tunnel according to an aspect of the additive manufacturing system.

[0030] FIG. **3**H shows a perspective view of an exemplary embodiment of a motorized transmission unit according to an aspect of the additive manufacturing system.

[0031] FIG. **4**A shows a schematic of an exemplary embodiment of a powder supply and delivery (PSD) system according to an aspect of the additive manufacturing system.

[0032] FIG. **4**B shows a perspective view of an exemplary embodiment of a powder hopper positioned on the frame according to an aspect of the additive manufacturing system.

[0033] FIG. **4**C-**1** shows a perspective view of an exemplary embodiment of a powder hopper according to an aspect of the additive manufacturing system.

[0034] FIG. **4**C-**2** shows a perspective view of an exemplary embodiment of a powder hopper according to an aspect of the additive manufacturing system.

[0035] FIG. **4**C-**3** shows a perspective view of an exemplary embodiment of a powder hopper according to an aspect of the additive manufacturing system.

[0036] FIG. **4**C-**4** shows a perspective view of an exemplary embodiment of a powder hopper with positioning legs according to an aspect of the additive manufacturing system.

[0037] FIG. **4**C-**5** shows a perspective view of an exemplary embodiment of the stability base and the positioning feet positioned on the frame according to an aspect of the additive manufacturing system.

[0038] FIG. **4**C-**6** shows a perspective view of an exemplary embodiment of an electric-pneumatic connection box according to an aspect of the additive manufacturing system.

[0039] FIG. **4**D-**1** shows a diagram of an exemplary embodiment of a linear vibration (LV) system of the PSD system according to an aspect of the additive manufacturing system.

[0040] FIG. **4**D-**2** shows a perspective view of an exemplary embodiment of the LV system of the PSD system according to an aspect of the additive manufacturing system.

[0041] FIG. **4**D-**3** shows a perspective view of an exemplary embodiment of the vibratory feeder box of the PSD system according to an aspect of the additive manufacturing system.

[0042] FIG. **4**E shows a perspective view of an exemplary embodiment of a diverter of the PSD system according to an aspect of the additive manufacturing system.

[0043] FIG. **4**F-**1** shows a perspective view of an exemplary embodiment of a recoater of the PSD system according to an aspect of the additive manufacturing system.

[0044] FIG. **4**F-**2** shows a perspective view of an exemplary embodiment of a doser of the PSD system according to an aspect of the additive manufacturing system.

[0045] FIG. **4**F-**3** shows a perspective view of an exemplary embodiment of a doser of the PSD system according to an aspect of the additive manufacturing system.

[0046] FIG. **4**F-**4** shows a perspective view of an exemplary embodiment of a doser with an ultrasonic sprinkler of the PSD system according to an aspect of the additive manufacturing system.

[0047] FIG. **4**F-**5** shows a perspective view of an exemplary embodiment of a doser with an ultrasonic sprinkler of the PSD system according to an aspect of the additive manufacturing system.

[0048] FIG. **4**F-**6** shows perspective views of exemplary embodiments of perforated plates of the doser according to an aspect of the additive manufacturing system.

[0049] FIG. **4**F-**7** shows a perspective view of an exemplary embodiment of a recoater coupled to a doser according to an aspect of the additive manufacturing system.

[0050] FIG. **4**F-**8** shows an exemplary schematic with corresponding images of a recoater in action according to an aspect of the additive manufacturing system.

[0051] FIG. **4**G-**1** shows a graph of experimental results of an exemplary embodiment of the PSD system according to an aspect of the additive manufacturing system.

[0052] FIG. **4**G-**2** shows a graph of experimental results of an exemplary embodiment of the PSD system according to an aspect of the additive manufacturing system.

[0053] FIG. **5**A shows a perspective view of an exemplary embodiment of an adaptive laser beam control (ALBC) system according to an aspect of the additive manufacturing system.

[0054] FIG. **5**B shows an exemplary block diagram of an embodiment of a method of using an algorithm for generating feature vectors for a given layer of a part to be manufactured according to an aspect of the additive manufacturing system.

[0055] FIG. **5**C shows an exemplary block diagram of an embodiment of a method of computing the distribution of the material powder for that layer and detecting the edge of the layer according to an aspect of the additive manufacturing system.

[0056] FIG. **5**D shows an exemplary block diagram of an embodiment of a method for computing the time for exposure to the laser beam from the laser according to an aspect of the additive manufacturing system.

[0057] FIG. **6**A shows a schematic of an exemplary embodiment of a dynamic gas flow (DGF) system according to an aspect of the additive manufacturing system.

[0058] FIGS. **6**B-**6**D show screenshots of process screens of an exemplary simulation to determine the embodiment of the DGF system according to an aspect of the additive manufacturing system.

[0059] FIG. **6**E shows exemplary screenshots of analysis by the simulation of the gas flow at multiple layers of the simulated build chamber according to an aspect of the additive manufacturing system.

[0060] FIGS. **6F1**-**6F4** show exemplary screenshots of outputs by the simulation presenting an optimized embodiment of the DGF system according to an aspect of the additive manufacturing system.

[0061] FIGS. **6G1-6G2** show perspective views of exemplary embodiments of the DGF system according to an aspect of the additive manufacturing system.

[0062] FIGS. **6H1-6H2** show exemplary screenshots of analysis by the simulation of the gas flow by embodiments of the DGF system of FIG. **6G1** with a lower gas inlet and an upper gas inlet according to an aspect of the additive manufacturing system.

[0063] FIG. **6H-3** shows an exemplary screenshot of analysis by the simulation of the gas flow from a top view by an embodiment of the DGF system according to an aspect of the additive manufacturing system.

[0064] FIGS. **6I-1-6I-2** show exemplary screenshots of analysis by the simulation of the gas flow by embodiments of the DGF system of FIG. **6G-2** with a gas flow only into a lower gas inlet according to an aspect of the additive manufacturing system.

[0065] FIGS. **6I-3-6I-4** show exemplary screenshots of analysis by the simulation of the gas flow by embodiments of the DGF system of FIG. **6G-2** with a gas flow only into an upper gas inlet according to an aspect of the additive manufacturing system.

[0066] FIGS. **6I-5-6I-6** show exemplary screenshots of analysis by the simulation of the gas flow by embodiments of the DGF system of FIG. **6G-2** with gas flow into an upper gas inlet and the bypass gas inlet according to an aspect of the additive manufacturing system.

[0067] FIGS. **6J-1-6J-2** show exemplary screenshots of analysis by the simulation of the gas flow by an embodiment of the DGF system of FIG. **6G-1** and an embodiment of the DGF system of FIG. **6G-2** according to an aspect of the additive manufacturing system.

[0068] FIGS. **6J-3-6J-4** show exemplary screenshots of analysis by the simulation of the gas flow by two different embodiments of the DGF system of FIG. **6G-2** according to an aspect of the additive manufacturing system.

[0069] FIGS. **6J-5-6J-6** show exemplary screenshots of comparison rendering output by the simulation of the gas flow by an embodiment of the DGF system of FIG. **6G-1** and an embodiment of the DGF system **600** of FIG. **6FG-2** according to an aspect of the additive manufacturing system.

DETAILED DESCRIPTION

[0070] The detailed description set forth below is intended as a description of various configurations of the subject technology and is not intended to represent the only configurations in which the subject technology may be practiced. The appended drawings are incorporated herein and constitute a part of the detailed description. The detailed description may include specific details for the purpose of providing a thorough understanding of the subject technology. However, the subject technology is not limited to the specific details set forth herein and may be practiced without these specific details. In some instances, structures and components are shown in block diagram form in order to avoid obscuring the concepts of the subject technology.

[0071] Referring to the drawings, FIG. **1** shows a schematic of an exemplary aspect of an additive manufacturing system **100**. FIG. **1** also presents the primary structural components of the additive manufacturing system **100**. These include a frame **104**, an additive manufacturing machine **102** disposed on the frame **104**, a processor **106** disposed on the frame **104** and electrically coupled to the additive manufacturing system **100**, a memory unit **108** electrically coupled to the processor **106** and containing instructions **110** to control the additive manufacturing system **100**. In some aspects of the additive manufacturing system **100**, the additive manufacturing system **100** further includes an interactive display unit (not shown in figure) electrically coupled to the processor **106** and configured to allow a user to control the processor **106** via the interactive display unit. In some aspects of the additive manufacturing system **100**, the interactive display unit is a touch-screen interface. In other aspects of the additive manufacturing system **100**, the interactive display unit is a display unit with manual tactile functional actuators (e.g., a keyboard) for controlling the processor **106**.

[0072] In the aspect of the additive manufacturing system **100** presented in FIG. **1**, the additive manufacturing machine **102** includes a build chamber **200**, a Z-axis levelling system **300** functionally connected to the build chamber **200**, a powder delivery system **400** functionally connected to the build chamber **200**, an adaptive laser beam control system **500** disposed within the build chamber **200**, and a dynamic gas flow system **600** disposed on the build chamber **200**. The additive manufacturing system **100** can include other components in addition to and is not limited to the components presented in FIG. **1**.

[0073] The aspect of the additive manufacturing system **100** presented in FIG. **1** is configured to perform the steps to create successive layers of material to form a three-dimensional object, including: supplying material powder to be fused by the adaptive laser beam control system **500** through the powder delivery system **400** and uniformly spreading the material powder on the build platform by a recoater **410** (explained in other sections of the application) of the powder delivery system **400**, maintaining an even layer of newly deposited material powder with the recoater **410**, targeting a particular area on a build platform **302** (explained in other sections of the application) of the Z-axis leveling system **300** to fuse the material powder with the laser to create a first layer of the part being built, lowering the build platform **302**, and spreading another layer of powder over the build platform **302** for the next layer of the part to be built.

Build Chamber

[0074] Referring to FIGS. **2**A and **2**B a schematic top view and a perspective view of an exemplary embodiment of the build chamber **200** according to an aspect of the additive manufacturing system **100**, are shown respectively. The embodiment of the build chamber **200** of FIG. **2** includes a housing **202** defined by four walls **204** with each having an interior wall surface **206**, a build platform opening **210** disposed on the housing **202** and configured to accommodate a build platform **302** of the Z-axis levelling system **300**, and a door **208**. In other embodiments of the build chamber **200**, the housing **202** can include more than four wall **204**.

[0075] In the embodiment of the build chamber **200** shown in FIGS. **2**A and **2**B, the housing **202** of the build chamber **200** accommodates the adaptive laser beam control system **500**, the recoater **410**, and a powder delivery system opening **212** present on a wall **204** of the housing **202**, for connecting the diverter **406** to a doser **408**. In some embodiments, the doser **408** can be mechanically connected to the recoater **410**. In some embodiments, the doser **408** and recoater **410** are independent components which are not mechanically connected to each other. In the embodiment of the build chamber **200** disclosed in FIG. **2**B, the walls **204** of the build chamber **200** can further be coupled to the dynamic gas flow system **600**. The build chamber **200** of FIGS. **2**A and **2**B can further include a roof, a floor, and a plurality of inlets and outlets (not shown in the figure) to facilitate movement of gas for the dynamic gas flow system **600**. In some embodiments of the build chamber **200**, the build chamber **200** further includes a viewing window (not shown in figure) for the user to view the formation of the three-dimensional object being manufactured by the additive manufacturing system **100**.

[0076] In some embodiments of the build chamber **200**, the build chamber **200** can further include a plurality of sensors (e.g., temperature sensor, oxygen sensor, pressure sensor, etc) to monitor and provide build chamber environmental conditions (e.g., temperature, oxygen level, pressure) feedback data to the processor **106** for necessary adjustments. In some embodiments of the build chamber **200**, the build chamber **200** is pressure sealed to a user-determined pressure threshold value. In this embodiment, the pressure inside the build chamber **200** is automatically maintained by a dynamic gas flow system **600** (controlled electrically by the processor **106**) disposed on the build chamber **200** and the pressure inside the build chamber **200** is monitored by a pressure sensor in communication with the processor **106**.

Z-Axis Leveling System

[0077] Referring to FIGS. **3**A, **3**B and **3**C, a schematic of an exemplary embodiment and perspective views of the Z-axis leveling system **300** according to an aspect of the additive manufacturing system **100** are shown. The disclosed aspect of the Z-axis leveling system **300** improves on conventional systems by reducing the time and skill required to achieve a level state of the build platform **302** and by reducing the part count and cost for building the Z-axis leveling system **300**.

[0078] In the embodiment of the schematic of the Z-axis leveling system **300** presented in FIGS. **3**A, **3**B and **3**C, the Z-axis leveling system includes a base **304**, the build platform **302**, and a vertical actuator **306** mechanically connected to the base **304**. The movement of the vertical actuator **306** is controlled by the processor **106** unit connected to the additive manufacturing machine **102** (shown in FIG. **1**). The Z-axis leveling system **300** of FIG. **3**A is configured to move the build platform **302** in a Z-axis into the build chamber **200** through the build platform opening **210** (refer to FIG. **2**) and support the build platform **302** when a component is being manufactured.

[0079] Referring to the embodiment of the Z-axis leveling system **300** presented in FIG. **3**C, the Z-axis leveling system **300** further includes a Z-axis tunnel **308** configured to accommodate the movement of the build platform **302** by the vertical actuator **306**. In the same embodiment, the vertical actuator **306** includes a height adjuster platform **318**, at least one vertical guide **314** disposed on the height adjuster platform **318**, a motorized transmission unit **316** disposed on the height adjuster platform **318** and connected to a vertical post platform **312**, at least one vertical post **310** mechanically coupled to the vertical post platform **312** and a base platform **342** (not shown in the figure) connected to the base **304**. This embodiment of the vertical actuator **306** includes an energy chain **325** configured for the movement of the vertical actuator **306**, a Y-axis bracing cover plate **322** and an X-axis bracing cover plate **320**, both configured to stabilize the Z-axis leveling system **300** during the vertical movement.

[0080] Referring to FIG. **3**D-**1**, perspective views of the build platform **302**, the base **304**, and a base platform **342** according to an aspect of the additive manufacturing system **100** are shown. The build platform **302** includes an upper side **324**, a lower side **356**, and four thru-holes **328**. In some embodiments, each of the four thru-holes **328** is disposed in a corner of the base **304**. In the embodiment of the build platform **302** presented in FIG. **3**D-**1**, the build platform **302** includes a powder bed **326** disposed on the upper side **324** of the build platform **302** on which the component is built. The lower side **356** of the build platform **302** is connected to a first side **332** of the base **304** via leveling cones **336** disposed on each corner of the base **304**. In this embodiment, a vertical axis of the leveling cone **336** is configured to be co-axial with the thru-holes **328** of the build platform **302**. The build platform **302** further includes at least one handle **330** disposed on the build platform **302** for a user to grip and remove the build platform **302** from the base **304**. In the embodiment of base **304** presented in FIG. **3**D-**1**, a second side **334** of the base **304** is mechanically coupled to the vertical actuator **306** via the base platform **342**. In some embodiments of the base platform **342**, the base platform **342** can include multiple detachable layers **340**, which can be added or removed to adjust the height of the base platform **342**. In the embodiments presented in FIG. **3**C**1**, the base **304**, connected to the vertical actuator **306** via the base platform **342**, is configured to lower the build platform **302** before each new layer of material powder is added to the powder bed **326** disposed on the upper side **324** of the base platform **342**.

[0081] The base **304** includes leveling cones **336** disposed in leveling corner threads **338** present in each corner as shown in FIG. **3**D-**1**. In some embodiments, the base **304** can further include additional leveling cones **336** disposed along the first side **332** of the base **304**. FIGS. **3**D-**2** and **3**D-**3** present side and top views of an exemplary embodiment of a leveling cone **336** according to an aspect of the additive manufacturing system **100**. The leveling cone **336** includes an upper portion **344** with a crowned surface **348** and a cylindrical lower portion **346** attached to the conical upper portion **344**. In the embodiment of the leveling cones **336** presented in FIGS. **3**D-**2** and **3**D-**3**, the upper portion **344** is conically shaped. The crowned surface **348** is slightly convex to allow for greater contact area with the corresponding leveling locator cavities **358** (refer to FIG. **3**D-**4**) disposed on the lower side **356** of the build platform **302**. In this embodiment of the leveling cone **336**, the upper portion **344** of the leveling cone **336** further includes a flat surface **350** surrounding an opening **354** extending the along the axis of the leveling cone **336**. In the embodiment presented in FIGS. **3**D-**2** and **3**D-**3**, the opening **354** includes a leveling portion **352** that allows the leveling cone **336** to be raised or lowered. In some embodiments of the leveling cone **336**, the leveling cone **336** can be raised or lowered via rotating a hex key placed in the opening **354**. In some embodiments of the leveling cone, the leveling portion **352** can include a threaded interior surface configured to secure the build platform **302** to the base **304** via a bolt (not shown in figure). In other embodiments of the leveling cone **336**, the opening

354 can accommodate a bolt configured to be tightened to a threaded surface in the leveling cone threads 338 disposed on the base 304.

[0082] Referring to FIG. 3D-4, a perspective view of the lower side 356 of an exemplary embodiment of the build platform 302 according to an aspect of the additive manufacturing system 100 is shown. In this embodiment, the lower side 356 of the build platform 302 includes leveling locator cavities 358 in each of the four corners of the build platform 302. In this embodiment, the lower side 356 of the build platform 302 further includes additional leveling locator cavities 358 along the perimeter or within the interior surface area. In some embodiments, the leveling locator cavities 358 can correspond to the locations and sizes of the leveling cones 336 on the base 304.

[0083] In FIG. 3D-4, four embodiments of the leveling locator cavities 358 are shown. The four embodiments of the leveling locator cavities 358 shown include a primary locator 360, a secondary locator 362, a tertiary locator 364, and a quaternary locator 366. The tertiary locator 364 and quaternary locator 366 each can be slightly oversized compared to their corresponding leveling cones 336 so predominately the tops/ends of their corresponding leveling cones 336 contact the tertiary locators 364 and quaternary locators 366. In the embodiment of the base shown in FIG. 3D-4, the tertiary locator 364 and quaternary locator 366 can be used for z-axis leveling only. In some embodiments of the build platform 302, the primary locators 360 and secondary locators 362 can be used for placing the build platform 302 in the X-axis and Y-axis directions. In some embodiments of the build platform 302, the build platform 302 can be easily removed to be machined flat.

[0084] In the embodiment of the build platform 302 shown in FIG. 3D-4, the secondary locator 362 includes extension slots 368 to make the locator cavity 358 not exactly circular, but rather an elongated cone. The elongated cone allows additional room for fitting the build platform 302 on the levelling cones 336. The extension slot 368 is configured to be aligned along a diagonal to maximize the elongated portion of the levelling cone 336 in the direction the build platform 302 may need to move (i.e. opposite the primary locator 360).

[0085] Referring to FIGS. 3D-3 and 3D-4, the crowned surface 348 of the leveling cone 336, the elongation of the secondary locator 362, and the enlarged locator cavities 358 (i.e., tertiary locator 364 and quaternary locator 366) can be configured to permit a looser tolerance on the machined center-to-center distances for the leveling cones 336 and the locator cavities 358.

[0086] In some embodiments of the build platform 302, the build platform 302, after being through many build cycles, can be subject to warping, and may need to be machined flat. The crowned surface 348 of the leveling cone 336, shown in FIG. 3D-3, provides greater contact area with the corresponding leveling locator cavities 358 even during warpage of the build platform 302.

[0087] Installing the build platform 302 shown in FIG. 3D-4 onto the base 304 via the leveling cone 336 shown in FIG. 3D-3 to achieve a level state includes the steps of placing the primary locator 360 over its corresponding leveling cone 336 first and placing the secondary locator 362 placed over its corresponding leveling cone 336 with the aid of the extension slots 368 present in the secondary locator 362. In these embodiments, the height of the leveling cone 336 can be increased or decreased with a hex key and checked with a gage block placed on the build platform 302 to give feedback when adjusting the height of the leveling cone 336. In some embodiments, the entire process to reach a level state can be configured to achieved in approximately 15 minutes. The leveling process can eliminate the need to place and remove the build platform 302 multiple times during leveling. In some embodiments, the build platform 302 can be placed and then leveled without any need to remove the build platform 302 until after the additive manufacturing processes is completed. The disclosed leveling process can advantageously eliminate the need for quantitative measurement during leveling and the use of numbers or calculations to adjust the build platform 302 to level.

[0088] Referring now to FIGS. 3E-3H, perspective views of various components of an exemplary embodiment of the vertical actuator 306 are shown.

[0089] FIG. 3E presents a perspective view of an exemplary embodiment of a height adjuster 370 of the build platform 302 according to an aspect of the additive manufacturing system 100. In the embodiment of the height adjuster 370 presented in FIG. 3E, the height adjuster 370 includes a base platform 342 mechanically connected to the base 304 and build platform 302, vertical posts 310 connecting the base platform 342 to the vertical post platform 312, vertical guide bearings 372 disposed on the vertical post platform 312 and the energy chain 325 secured in a cable management bracket 374 during height adjustment via a motorized transmission unit 316 (not shown in FIG. 3E). The height adjuster 370 can include other components in addition to and is not limited to the components presented in FIG. 3E.

[0090] Referring now to FIG. 3F, a perspective view of an exemplary embodiment of the vertical actuator 306 with vertical guides 314 is shown. In the embodiment of the height adjuster 370 shown in FIG. 3E, the upper ends 378 of vertical guides 314 are connected to the base platform 342 via vertical guide connectors 376 and the bottom ends 380 of the vertical guides 314 are connected to the height adjuster platform 318 via the vertical guide connectors 376. In the same embodiment of FIG. 3F, the vertical guides 314 are configured to fit through the vertical guide bearings 372 disposed on the vertical post platform 312. This enables and restricts the vertical movement of the vertical post platform 312 along the length of the vertical guides 314 leading to the height adjustment. In some embodiments, the vertical guides 314 are detachably connected to the vertical guide connectors 376 and can be removed for replacement.

[0091] Referring now to FIG. 3G, a perspective view of an exemplary embodiment of a Z-axis tunnel 308 is shown. In the embodiment of the Z-axis tunnel 308 shown in FIG. 3G, the Z-axis tunnel 308, comprising an interior wall 382, is configured to allow the build platform 302, base 304, base platform 342, and vertical posts 310 to vertically translate across a length of the Z-axis tunnel 308. In some embodiments, the Z-axis tunnel 308 is made of a single-piece molded material. In some embodiments, the Z-axis tunnel 308 is made of a single-piece machine cut heat-resistant metal. In some embodiments, the interior wall 382 of the Z-axis tunnel 308 is surface treated to allow smoother vertical translation of the height adjuster 370 across a length of the Z-axis tunnel 308.

[0092] Referring now to FIG. **3**H, a perspective view of an exemplary embodiment of the motorized transmission unit **316** is shown. In this embodiment, the motorized transmission unit **316** includes a motor **384** disposed on a transmission subassembly base **386**, a ball screw **390**, and bellows cover **388**. Motor **384** is connected to ball screw **390** by a belt **396**, where motor **384** adjusts a vertical height of ball screw **390** through the belt **396**. The movement of the ball screw **390** can result in vertical movement of the vertical post platform **312** and base platform **342**, leading to the height adjustment of build platform **302**. In the same embodiment, ball screw **390** is mechanically connected to the vertical post platform **312**. In various embodiments of the motorized transmission unit **316**, actuating the motor **384** can result in the movement of the ball screw **390** which in turn causes the vertical translation of the vertical post platform **312** along the length of the vertical guides **314**. In this embodiment, the motorized transmission unit **316** is configured to removably fit into the height adjuster platform **318**.

[0093] In previous Z-axis leveling system, the motorized transmission unit was only accessible through an access panel and could not be removed as a unit. The embodiment of the motorized transmission unit **316** shown in FIG. **3**H is easily removed as a unit from the base assembly, as is shown in FIG. **3**G. The motorized transmission unit **316** can therefore have the belt **396** pre-tensioned before being installed to reduce installation and setup time. Further, once the motorized transmission unit **316** is disconnected from height adjuster platform **318**, it can lift itself out of the height adjuster platform **318** if the top portion of the motorized transmission unit **316** is bolted to vertical post platform **312**. This is advantageous because the motorized transmission unit **316** is heavy and this feature allows easier access to the belt **396** underneath, especially when the additive manufacturing system is at customer locations.

[0094] In the embodiment of the motorized transmission unit **316** shown in FIG. **3**H, the motorized transmission unit **316** further includes a transmission subassembly cover plate **392** to secure the motorized transmission unit **316** in the height adjuster platform **318**. In some embodiments of the motorized transmission unit **316**, the transmission subassembly cover plate **392** can be secured to the height adjuster platform **318** with countersunk screws (not shown in FIG. **3**H).

Powder Supply and Delivery System

[0095] Referring to the drawings, FIG. **4**A shows a schematic of an exemplary embodiment of a powder supply and delivery (PSD) system **400** according to an aspect of the additive manufacturing system **100**. The PSD system **400** of FIG. **4**A is configured to supply material powder to the build platform **302** of the Z-axis leveling system **300** needed to create successive layers of material to manufacture a three-dimensional object. FIG. **4**A also presents the primary structural components of an embodiment of the PSD system **400**. These include a powder hopper **402**, a linear vibration system **404**, a diverter **406**, a doser **408**, and a recoater **410**. The PSD system **400** is also electrically coupled to the processor **106**, where the memory unit **108** coupled to the processor **106** includes the instructions **110** to control the PSD system **400**. The PSD system **400** presented in this disclosure aims to reduce the number of subsystems working in series to improve reliability of the powder supply to the build platform **302**. The PSD system **400** can include other components in addition to and is not limited to the components presented in FIG. **4**A.

[0096] In the aspect of the PSD system **400** and the embodiments of the components of the PSD system **400** discussed in FIGS. **4**A-**4**G-**2**, the PSD system **400** is configured to have a powder hopper **402** (discussed below) located above the build platform **302** so the delivery of the material powder to manufacture the three-dimensional component could be supplied to the build platform **302** utilizing gravity.

[0097] Referring now to FIG. **4**B, a perspective view of an exemplary embodiment of a powder hopper **402** positioned on the frame **104** is shown. In this embodiment, the powder hopper **402** includes a body **414** with an inlet **412** for filling the powder hopper **402** with the material powder and an outlet **416** for delivery of the material powder from the powder hopper **402**, positioning legs **418** disposed on the body **414**, and an electric-pneumatic connection box **420** electrically connected to the processor **106** and the outlet **416** to control the operations of the powder hopper **402**. In some embodiments, the positioning legs **418** of the powder hopper **402** can be configured to be removably connected to the frame **104** of some aspects of the additive manufacturing system **100**. In this embodiment of the powder hopper **402** shown in FIG. **4**B, the powder hopper **402** is configured to hold an increased volume of the material powder, increased angle for reliable material powder delivery via the outlet **416**, and improved aesthetics as discussed in the below paragraphs. In the embodiment of the powder hopper **402** presented in FIG. **4**B, the powder hopper **402** can be configured to have a volume of **60**L for containing the material powder.

[0098] Typically, the material powder can have a tendency to be stuck in the corners of the interior walls of the powder hopper **402**. In order to prevent the latter and to ensure that a usable volume of the material powder in the powder hopper **402** is close to the volume of the material powder contained in the powder hopper **402**, in the embodiments of the powder hopper **402** presented in FIGS. **4**C-**1**-**4**C-**3**, a corner formed by the interior walls **422** of the powder hopper can be configured to have a compound angle that is less than a flat wall angle of the interior walls **422**. In some embodiments, the compound angle is configured to be 35° for reliable emptying of the material powder from the powder hopper.

[0099] In some embodiments of the powder hopper **402**, the powder hopper **402** can have increase compound angles and wall angles with increased number of interior walls **422**. In the embodiment of the powder hopper **402** presented in FIG. **4C-3** has 8 interior walls **422**. In some embodiments of the powder hopper **402**, the powder hopper **402** can include more than 8 interior walls (i.e., 10, 12, 16, 18, 20 or more interior walls). The compound angle of a truncated pyramid approaches the flat angle as the number of interior walls **422** increase, with infinite interior walls **422** creating a cone. In some embodiments of the powder hopper **402**, the number of interior walls **422** can be increased by adding inserts. In some embodiments (such as the embodiment of FIG. **4C-3**), the powder hopper **402** can be configured to have 8 interior walls **422** as the preferred embodiment to increase the compound angle with only a slight increase in the flat wall angle, resulting in improved material powder emptying. In the embodiments of the powder hopper **402** presented in

FIGS. **4C-1-4C-3**, the powder hopper **402** further includes a flow controller **424** disposed at the outlet **416** to regulate the flow of the material powder.

[0100] Referring to FIG. **4C-4**, a perspective view of an exemplary embodiment of a powder hopper **402** with positioning legs **418** is shown. In this embodiment, the positioning legs **418** are disposed on the body **414** of the powder hopper **402**. In the embodiment of the FIG. **4C-4**, the powder hopper **402** includes four positioning legs **418** coupled to a stability base **426** and four positioning feet **428**, corresponding to each of the four positioning legs **418**, disposed on the stability base **426**. The positioning feet **428** are configured to fit the powder hopper **402** on the frame **104**. In this embodiment of the powder hopper **402** shown in FIG. **4C-4**, the positioning feet **428**enable the powder hopper **402** to be removably coupled to the frame **104**.

[0101] Referring to FIG. **4C-5**, a perspective view of an exemplary embodiment of the stability base **426** and the positioning feet **428** positioned on the frame **104** is shown. In this embodiment, the positioning feet **428** are configured to fit in a positioning hole **430** on the frame **104**, removably coupling the powder hopper **402** to the frame **104**. In some embodiments of the powder hopper **402**, the positioning feet **428** can be conical in shape and the positioning holes **430** may be corresponding conical shapes to accommodate the positioning feet **428**. In some embodiments of the powder hopper **402**, the shape of the positioning feet **428** can be hemispherical, pyramidal, or oblong, or any other shape, with a corresponding shaped positioning hole **430** on the frame **104** to accommodate the positioning feet **428**. In some embodiments, a radius of the positioning feet **428** can be 30 mm to correspond with typical positioning accuracy of an operator. In some embodiments, the positioning feet **428** and positioning holes **430** can be made of plastic to allow them to slide relative to each other while maintaining friction at a manageable level to ensure a secure fit of the powder hopper **402** on the frame **104**.

[0102] Referring to FIG. **4C-6**, a perspective view of an exemplary embodiment of the electric-pneumatic connection box **420** is shown. In this electric-pneumatic connection box **420** includes at least one electrical connection **432** and at least one pneumatic connection **434** disposed on the electric-pneumatic connection box **420**. In some embodiments, the at least one pneumatic connection **434** can be configured to act as an equalization line to prevent vacuum formation. In some embodiments, the at least one pneumatic connection **434** can be configured to act as an argon supply line to flood the internal volume. In some embodiments, the at least one electrical connection **432** can be configured to act as an electrical supply for humidity and oxygen sensors.

[0103] Referring to the embodiment of FIG. **4C-6**, the electric-pneumatic connection box **420** can be located at the front of the powder hopper **402**. In some embodiments, the electrical-pneumatic connection box **420** can be disposed at another location besides the front of the powder hopper **402** and be configured to be accessible by an operator. The disclosed electric-pneumatic connection box **420** of FIG. **4C-6** can be configured to have quick-connect/disconnect connections. In some embodiments, the electric-pneumatic connection box **420** can be configured to have color coding for each connection in order to make it easier for the operator to know which line to connect to which port, with no restriction of which colors can be used. In some embodiments, the connections can also be used when the loaded powder hopper **402** are in storage, such as to monitor moisture removal or other environmental monitoring to ensure the stability of the material powder (e.g., cost of material powder can be approximately $60,000).

[0104] Referring now to FIG. **4D-1**, a diagram of an exemplary embodiment of the linear vibration (LV) system **404** of the PSD system **400** is shown. In the diagram shown in FIG. **4D-1**, the LV system **404** includes a vibratory feeder box **436** which has a feeder box inlet **438** to receive the material powder from the powder hopper and a vibratory feeder box outlet **440** to output the material powder to the diverter **406** (described in paragraphs below). In this embodiment, the vibratory feeder box **436** further includes a vibration mechanism **442** mechanically connected to the vibratory feeder box **436** to provide vibration force to the material powder in the vibratory feeder box. In this embodiment, vibration force alone drives powder motion along a path of delivery between the feeder box inlet **438** and the feeder box outlet **440**. The vibration force provided by the vibration mechanism **442** is configured to make the powder particles of the material powder to jump up and move forward, while gravity pulls the particles back down and the process repeats, causing the particles to hop along the length of the vibratory feeder box **436**. In this embodiment, the movement of the powder particles is controlled by the vibration mechanism **442**, where powder particles move when the vibration mechanism **442** is active and immediately stop when vibration mechanism **442** is inactive. In some embodiment, the vibration feeder box can be configured to not allow material powder flow through feeder box inlet **438** when vibration is not active via the angle of repose of the pile of the material powder in the vibratory feeder box **436**. In some embodiments, the frequency and amplitude of the vibration mechanism **442** can be set via phase controllers through the processor **106**. The embodiment of the LV system **404** shown in FIG. **4D-1** is configured to not contain translating or rotating parts that could be fouled by material powder. The embodiment of the LV system **404** shown in FIG. **4D-1** allows for predictable conveyance of the material powder, which results in controllability of the powder being delivered. Material powder movement with the LV system **404** is less sensitive and more predictable to powder density than gravity conveyance systems.

[0105] Referring to FIG. **4D-2**, a perspective view of an exemplary embodiment of the LV system **404** of the PSD system **400** is shown. In this embodiment, the LV system **404** includes vibratory feeder box **436**, the feeder box inlet **438**, and the feeder box outlet **440** and the vibration mechanism **442** disposed on a first surface **444** of the vibratory feeder box **436**. The LV system **404** is configured to reduce the vibration of sensitive components throughout the additive manufacturing system **100**. In this embodiment, the feeder box inlet **438** and the feeder box outlet **440** further include flexible bellows **448**, containing grooves **450**, configured to effectively isolate vibration from the build chamber **200**. In some embodiments, the flexible bellows can dissipate close to 100% of vibrations. In this embodiment, the flexible bellows **448** mounted on the vibratory box inlet **438** includes a nozzle (not shown in figure) internally to minimize the material powder touching and remaining in the grooves **450** of the flexible bellows **448**. In this embodiment, the vibratory feeder box **436** is coupled to frame **104** via a rigid mount (not shown in the figure) connecting a vibratory feeder box base **446** to the frame **104**. In some embodiments, the vibratory feeder box base **446** can be coupled to a large mass to dissipate high frequency vibrations, where the large mass is then mounted to the frame **104**.

[0106] Some embodiments of the vibratory feeder box **436** can allow for vibration frequency control and can be capable of handling more than a 10-pound load. Some embodiments of the of the vibratory feeder box **436** can include internal baffles (not shown in figure) placed at specific locations and distances to limit material powder conveyance.

[0107] Referring to FIG. **4**D-**3**, another embodiment of the vibratory feeder box **436** is shown. In this embodiment, the vibration mechanism **442** of the vibratory feeder box **436** is coupled to the vibratory feeder box base **446**, making it easier to securely mount the vibratory feeder box **436** to the frame **104**. In some embodiments, the vibration mechanism **442** is coupled to a base frame **452** (shown in FIG. **4**D-**3**) for coupling to the frame **104** to further isolate vibration forces from the additive manufacturing system **100**. In this embodiment, the first surface **444** of the vibratory feeder box **436** includes a sight-glass **456** and a removable lid **454**. The sight glass **456** is configured to allows visual inspection of the inside of the vibratory feeder box **436** to check for obstructions. The removable lid **454** is configured to allow for access to the internal surfaces of the vibratory feeder box **436** to aid in cleaning. In some embodiments of the vibratory feeder box, a floor (not shown in the figure) of the vibratory feeder box **436** can have a 3° decline to encourage the flow of the material powder.

[0108] Referring to FIG. **4**E, a perspective view of an exemplary embodiment of the diverter **406** is shown. In this embodiment, the diverter **406** is configured to couple to the feeder box outlet **440** via a diverter inlet **457***a*, receive material powder from the feeder box outlet **440** into the diverter body **459**, and distribute the material powder to a required width of the build platform **302** via the diverter outlet **457***b*. In this embodiment, the diverter **406** is used to laterally distribute powder by converting the centralized cylindrical material powder flow coming from the feeder box outlet **440** into a sheet-like flow equal in width to the build platform **302**. In some embodiments such as the embodiment of FIG. **4**E, the lateral distribution of the material powder can be achieved by distributed powder channels **458** in the diverter. In some embodiments, the diverter **406** can have powder platforms (not shown in figure) at different levels to distribute the material powder laterally to the width of the build platform **302**.

[0109] Referring to FIG. **4**F-**1**, a perspective view of an exemplary embodiment of the recoater **410** is shown. In the embodiment shown in FIG. **4**F-**1**, the recoater **410** is moveably disposed in the build chamber **200** (secured to the interior wall surface **206** of one of the walls **204** of the build chamber **200** via a wall bracket **410***a* and a bracket stabilizer **410***b*) and is configured to distribute the material powder received from the diverter **406** in an even layer on the build platform **302**. In the embodiment shown in FIG. **4**F-**1**, the recoater **410** is further coupled to a doser **408** configured for receiving the material powder from the diverter **406** and split the material powder into a plurality of doses, where each dose corresponds to a layer of the component to be manufactured. Each dose, a user-defined amount of the received material powder, is configured to be spread evenly on the build platform **302** by the recoater **410**. In some aspects of the additive manufacturing system **100**, the doser **408** and recoater **410** can be independent of each other and not coupled to each other.

[0110] One embodiment of the doser **408** can include a blade style valve (as shown in FIG. **4**F-**1** denoted by a horizontal blade **460**) to limit the material powder flow to the build platform **302**. In the embodiment of the doser **408** with the blade style valve, a pneumatic actuator, a blade-shaped angle iron, and a 3D printed nozzle can be used to achieve a controlled valve by translating the blade under the nozzle. In this embodiment of the doser **408**, the gap between the top of the blade and the bottle of nozzle is configured to be approximately 1 mm gap. This embodiment of the doser **408** can be configured to control the material powder flow and to also stop the powder flow based to the angle of repose of the material powder in the doser **408**. In other embodiments of the doser **408**, the gap between the top of the blade and the bottle of nozzle can be configured to be in range of 0 mm to 2 mm.

[0111] Referring to FIGS. **4**F-**2**-**4**F-**5**, perspective views of an exemplary embodiments of a doser **408** are shown. In this embodiment shown in FIGS. **4**F-**2**-**4**F-**5**, the doser **408** is configured to receive the material powder (from the diverter **406**) via the doser inlet **462** into a doser reservoir **464** and deposits the material powder on to the build platform **302** via a perforated plate **468**, disposed at the doser outlet **466**, containing an array of small openings. In the embodiment shown in FIGS. **4**F-**4** and **4**F-**5**, the doser outlet **466** further includes an ultrasonic sprinkler **466***a* to deposit the material powder to the build platform **302** via ultrasonic vibrations. In the embodiments of the doser **408** shown in FIGS. **4**F-**4** and **4**F-**5**, activating or ceasing the ultrasonic vibration acts as a "valve" that opens/closes to encourage the material powder to flow or stop. This feature employs the angle of repose of powder between the underside of the perforated plate **468** (or slotted) and the spreading substrate (i.e., the build platform **302**, previously spread layer of material powder on the build platform **302** or solidified additive manufacturing part) to dose per layer. In some embodiments, it was determined that using perforated plates **468** with 0.8 mm slots by 4 mm long and 4 mm spacing, the material powder quickly ceased to flow as desired. In the same embodiment, the material powder that did pass and was deposited on the build platform **302** was sufficiently smoothed via an electrode planer **482** (described in paragraphs below).

[0112] FIG. **4**F-**6** presents perspective views of two different embodiments of perforated plates **468** with staggered holes (left) and straight holes (right). Referring to FIG. **4**F-**6**, different embodiments of perforated plates **468** with different dimensions can be used to both aid and control the material powder flow and control the powder flow.

[0113] FIG. **4**F-**7** presents a perspective view of an exemplary embodiment of the recoater **410** coupled to the doser **408**. In this embodiment, the recoater **410** is configured to be adjustable in terms of the dosed volume/mass to allow both optimization of material powder-use efficiency and different layer heights. The recoater **410** is able to deliver a known volume of material powder utilizing the substrate as the lower constraint of the material powder heap's height, the material powder's internal resistance to shear, and the known angle of repose. In this embodiment of the recoater **410**, the recoater **410** comprises a valve system **470** configured to stop the material powder flow as the recoater **410**

moves away from the dosing location. In this embodiment, the valve system **470** includes the horizontal blade **460** (as part of the doser **408**), a compression spring **474** wound around a compression shaft **476**, and a shaft guide **478**. In some embodiments of the valve system **470**, bellows (not shown in the figure) can be installed on the shaft guide **478** to prevent material powder ingress.

[0114] FIG. **4F-8** shows an exemplary schematic with corresponding images of the recoater **410** in action. In the left of FIG. **4F-8**, the recoater **410** in a start position where the recoater **410** has received the material powder from the diverter and the horizontal blade **460** is situated approximately 1 mm below a nozzle **480**, located at the doser outlet **466**. In the center of FIG. **4F-8**, the recoater **410** is shown in an open position during which the compression shaft **476** of the valve system **470** is depressed via the shaft guide **478**, allowing one user-define dose of material powder to flow from the nozzle **480** to the build platform **302**. In the right of FIG. **4F-8**, the recoater **410** is a coating position where the depression of the compression shaft **476** is removed when the recoater **410** is moving, resulting in the compression shaft **476** moving outward due to the decompression of the compression spring **474** and moved the horizontal blade **460** to close the flow of the material powder. In this embodiment, the electrode planer **482** of the recoater **410** spreads the material powder deposited on the build platform **302** during the open position of the recoater **410** to form a layer of the material powder on the build platform **302**. The recoater **410** is back in the start position after spreading the layer of the material powder on the build platform **302** and is configured to restart the process of spreading a second layer of the material powder on the build platform **302**. In some embodiment, adjusting the amount of material powder that is dosed can be done for every layer with feedback, such as a user viewer camera and a simple edge detection image analysis technique. In some embodiments, precise control of the material powder dose can be achieved through control of linear motion of the horizontal blade **460**.

[0115] Referring to FIGS. **4G-1-4G-2**, exemplary graphs (**484** and **486**) of experimental test results (in comparison with currently available rotary dosing systems of the material powder in the industry) of the powder dosing via the embodiment of the valve system **470** of FIG. **4D6** are shown.

Adaptive Laser Beam Control System

[0116] Referring to the drawings, FIG. **5**A shows a schematic of an exemplary embodiment of an adaptive laser beam control (ALBC) system **500** according to an aspect of the additive manufacturing system **100**. In the embodiment of the ALBC system **500** presented in FIG. **5**A, the ALBC system **500** is disposed in the build chamber **200** and is configured to selectively use a laser beam on the build platform **302** to selectively fuse layers of material powder to additively manufacture an object layer-by-layer. FIG. **5**A also presents the primary structural components of an embodiment of the ALBC system **500**. These include a laser **502**, at least one mirror galvanometer **504** to direct a laser beam from the laser **502** to the material powder on the build platform **302**, and a monitoring system **506** coupled to the processor **106** and configured to monitor the functionality of the ALBC system **500** (i.e., environmental conditions of the build chamber **200** when the ALBC system **500** is functioning, functionality of the laser **502**, and the at least one mirror galvanometer **504**). In some embodiments, the functionality of the laser **502** includes the parameters of the laser **502** including wavelength of the laser **502** and intensity of the laser **502**. In some embodiments, the environmental conditions of the build chamber **200** monitored by the monitoring system **506** include temperature, humidity, and oxygen level.

[0117] The ALBC system **500** is also electrically coupled to the processor **106**, where the memory unit **108** coupled to the processor **106** includes the instructions **110** to control the ALBC system **500**. In some embodiments, the monitoring system **506** can include a plurality of sensors (i.e., heat sensor, light sensor, etc.) for gathering feedback adjustment data regarding the functionality of the ALBC system **500** and delivering to the processor **106**. The processor **106** is configured to adjust the functionality of the ALBC system **500** based on the feedback adjustment data and further direct user input data. In other embodiments, the monitoring system **506** can also include a visual monitoring system (i.e., video camera) to provide a live video feed of the functionality of the laser to the user via a display connected to the processor **106**.

[0118] In some embodiments, the laser beam is delivered by the laser **502** at a wavelength between 400 nm-500 nm. In some embodiments, the laser beam is delivered by the laser **502** at a wavelength between 500 nm-600 nm. In some embodiments, the laser beam is delivered by the laser **502** at a wavelength greater than 600 nm. In some embodiments, the laser beam is delivered by the laser **502** at a wavelength of 1070 nm. The ALBC system **500** can include other components in addition to and is not limited to the components presented in FIG. **5**A.

[0119] In the embodiment of the ALBC system **500** presented in FIG. **5**A, the ALBC system **500** uses dynamically applied process parameter micro-adjustments to the parameters of the laser **502** and machine learning models to improve the quality of the part to be manufactured by the additive manufacturing system **100**. The ALBC system **500** of FIG. **5**A is configured to combine hardware monitoring of live processes, data transformation, machine learning, and dynamic application of adjustments during a live manufacturing of a part in order to apply online, high-resolution adjustments to a build. Additionally, the ALBC system **500** also enables a highly flexible, "open loop" printing process for any other method of providing high-resolution parameter adjustments.

[0120] This embodiment of the ALBC system **500** of FIG. **5**A also employs a software to compute mechanistic features of a toolpath of an additive manufacturing system **100**, which is initially fused with direct on-axis data acquisition to train a machine learning model. After the features of a toolpath are distilled and an algorithm is created, thereafter the same features can be generated for any toolpath on any part to produce high-resolution parameter adjustments to correct for predicted build imperfections, such as adapting the parameters of the laser **502** during a build to prevent imperfections. During the manufacturing of a part, the machine-control aspects of the software of the embodiment of the ALBC system **500** of FIG. **5**A will apply the feature corrections discussed above, as well as general parameter correction files from any source in a compatible format and apply them dynamically to adjust printing process parameters at microsecond-level intervals.

[0121] Referring now to FIG. **5**B, an exemplary block diagram of an embodiment of a method **510** of using an algorithm for generating feature vectors for a given layer of a part to be manufactured is shown. In this embodiment, the method **510** includes providing a thread scheduler **512**, where each thread of the thread scheduler incorporates a unit of execution corresponding to each layer for the part to be manufactured. The thread scheduler is configured to manage three dimensional (3D) build data **514** of the part to be manufactured. For each layer to be built, the method **510** further includes inputting a toolpath **516** comprising an ordered sequence of X and Y axis data for the part to be manufactured, rasterizing the ordered sequence from the tool path file into a set of pixels defining a constant length and width of the layer **518**, computing a distribution of the material powder for that layer and detecting the edge of the layer **520**, computing the time for exposure to the laser beam **522**, and finally, outputting a file containing feature vectors **524**.

[0122] In some embodiments of the method of FIG. **5**B, the algorithm can use a mathematical notation to compute the worst-case time complexity (i.e, how long an algorithm takes to run). In some embodiments of the method of FIG. **5**B, the mathematical notation to compute the worst-case time complexity is a "Big O Notation" (incorporated by reference and commonly known to a person skilled in the art). In some embodiments of the method of FIG. **5**B, a part with the dimensions of 10×15×10 mm needs the algorithm run time of 10 min to compute mechanistic features of an additive manufacturing machine toolpath, with time complexity approaching linear O(n) and enhanced flexibility in its data representation. For comparison, prior methods to create an algorithm to compute mechanistic features of an additive manufacturing machine toolpath may take a prohibitively long time, such as greater than 30 hours for a roughly 10×15×10 mm part, and the prior algorithms have with O(n2) quadratic time complexity and had low flexibility in its data structure implementation.

[0123] Referring to the method of FIG. **5**B, the algorithm further includes a machine-control for generating the exact machine toolpath at build-time. In this embodiment, during the live manufacturing of the part, the monitoring system **506** (presented in FIG. **5**A) can provide toolpath correction files as input to the method of FIG. **5**A, allowing precision in laser commands, in which parameters can be adjusted a layer at a time (i.e dynamic modeling). For the current embodiment of FIG. **5**B, the input toolpath correction file format relates an (xs, ys), (xe, ye) region to a parameter correction (such as laser power or profile for example).

[0124] In some embodiments, other toolpath correction files that relates a point in the toolpath to an adjustment can be used as a toolpath correction input. In some embodiments, the toolpath correction files can be json files that are arbitrary-sized collections of xy-region-start, xy-region-end, and/or laser-power-correction % data, and csv files that are a grid of laser power corrections, plus metadata describing the size of each grid tile of the specific layer. In some embodiments of the method of FIG. **5**B, a toolpath correction file can be a user defined external toolpath correction files that can have an association of locations to a scalar modifier, allowing for more advanced machine users to define their own external correction files, which can either be preprocessed before the build, or generated during the build. In some embodiments of the method of FIG. **5**B, the user defined external input can include the modification of parameters in the input file including, and not limited to, laser power, speed, profile (spot size), hatch distance and location.

[0125] Referring to FIG. **5**C, an exemplary block diagram of an embodiment of the method **530** of computing the distribution of the material powder for that layer and detecting the edge of the layer **520** (refer to FIG. **5**B) is shown. In this embodiment, the steps to this method, using a distribution and edge detection algorithm, include reading the input toolpath data **532**, converting the input toolpath data into plurality of points **534**, mapping into each point of the plurality of points to a tile on a grid to identify grid data corresponding to each layer **536**, storing grid data for each layer of the part to be manufactured **538**, identifying, for each point, the presence of solid material to identify if a point is an edge detection point (i.e., defined as a constant and represents evenly-spaced points in concentric planes about a line of length D directly below the current point and normal to the X, Y plane) or a solid distribution point (i.e., defined as a constant and represents evenly spaced points along the surface of a lower half-sphere) using the 3D data structure managed by the thread scheduler (refer to FIG. **5**A) **540**, and determining distribution of material powder and the edge of each layer **542**.

[0126] In this embodiment of the method **530** of **5**C, the method **530** retains the overall O(n) linear performance and reduces the memory requirements. The method **530** of this embodiment also advantageously leaves room for further developments as the resolution of the each of the layer's image can be freely modified without invalidating the algorithm.

[0127] Referring to FIG. **5**D, an exemplary block diagram of an embodiment of the method **550** for computing the time for exposure to the laser beam from the laser ("laser time") **522** (refer to FIG. **5**A) is shown. The method **550** of FIG. **5**D, using a laser time calculation algorithm, includes the steps of preprocessing the input toolpath data into spatially located regions (i.e. "buckets") **552** comprising a plurality of points in each layer, identifying a designated point from the plurality of points as representation of that "bucket" **554**, measuring a distance from the designated point to a target point in each region **556**, identifying the minimum value in each region, sorting values in each region to a sector and a ring corresponding to the points in buckets in each layer, and outputting vector values **558**.

[0128] In this embodiment of FIG. **5**D, each point in the layer are portioned into spatially local regions (or "buckets") in O(n) linear time, where only the points near the current point are considered for calculations. This results in an overall complexity reduction to O(nm) time and O(n) memory for the entire toolpath. In addition to reducing the complexity class, the absolute number of distance calculations (which are computationally expensive) are also significantly reduced, since only points that are potentially significant are checked (i.e., points that are too far from the target point to have any possibility of affecting the result are automatically excluded).

Dynamic Gas Flow System

[0129] Optimal gas flow is critical for an additive manufacturing system **100** that uses an irradiation device (i.e., the ALBC system **500**). Optimal gas flow conditions may vary, but are usually uniform flow, laminar flow, and relatively high volumetric flow to remove particulates from the build chamber **200** or around the irradiation device. Referring to FIG. **6**A, a schematic of an exemplary aspect of a dynamic gas flow (DGF) system **600** is shown. The DGF is configured to dynamically adjust the gas flow in the build chamber **200** to optimize the function of the additive manufacturing system **100** via removal of particulates and prevention of impairment of the functioning of the laser **502** of the ALBC system **500**.

[0130] In the embodiment of the DGF system **600** shown in FIG. **6**A, The DGF system **600** comprises at least one gas inlet **602**, at least one gas outlet **608**, at least one bypass gas inlet **610**, a dynamic flow surface **604** disposed within the build chamber **200** and configured to facilitate a flow of the input gas and a flow of the output gas, and a gas flow management system **606** to provide feedback on conditions in the build chamber **200** to adjust operation of the DGF system **600**. The feedback from the gas flow management system **606** can include, for example, during a recoating process, gas flow may be reduced, redirected, or interrupted to avoid powder erosion from gas flow acceleration and turbulence caused by the recoater **410**. Another example of the feedback includes increasing the volumetric flow rate in situations where there is a high particulate generation by a large melted cross-sectional area—or be increased up and down depending on the location of the laser **502** in a given time step. The DGF system **600** is also electrically coupled to the processor **106**, where the memory unit **108** coupled to the processor **106** includes the instructions **110** to receive feedback from the gas flow management system **606** and control the DGF system **600**. The DGF system **600** can include other components in addition to and is not limited to the components presented in FIG. **6**A.

[0131] In some embodiments of the DGF system **600**, the DGF system **600** can direct the gas supply to the gas inlet **602** into the build chamber **200** and remove the gas from the build chamber **200** through gas outlet **608**. In different embodiments, a different number of gas inlets **602** and gas outlets **608** may be selectively used to create different flow paths, thereby permitting better gas flow angles for certain builds or to avoid the architecture of the build chamber **200** (including the recoater **410**). In some embodiments of the DGF system **600** can be configured to pump an inert gas (e.g., Argon) into the build chamber **200** via the gas inlet **602** to purge oxygen gas from the build chamber **200** via the gas outlets **608** until a user determined target threshold pressure is reached in the build chamber **200** and the build chamber **200** is sealed. In some embodiments of the DGF **600**, the DGF **600**, via the instructions **110** stored in the memory unit **108** of the processor **106**, is configured to automatically pressurize the build chamber **200** to a target threshold pressure.

[0132] In some embodiments of the DGF system **600**, the gas inlets **602** can be used to provide primary gas flow for removing particulates from the build platform **302**, for suppressing gas flow recirculation, for directing particulates away from the laser **502**, and/or for providing flow across the irradiation device transmission surface to keep it functioning properly. In various embodiments of the DGF system **600**, the DGF system **600** can be configured to promote gas flow away from the laser **502** and not recirculating in the area of the laser **502** to prevent impeding the function of the laser **502** and to have relatively high gas flow rates around the build platform **302** (i.e., on the powder bed **326**) to remove particulates.

[0133] In some embodiments of the DGF system **600**, the gas inlets **602** and gas outlets **608** can be used to maintain a target-pressure inside the build chamber **200**. In this embodiment, a user can input the target-pressure via the processor **106** and the primary gas flow (i.e. an inert gas like argon) via the gas inlet **602** can be used to pressurize the build chamber **200** and the gas outlets **608** can be used to remove any oxygen (i.e., the concentration of oxygen gas in the build chamber can be measure via oxygen sensors) in the build chamber **200**. In this embodiment of the DGF system **600**, a pressure sensor (part of the gas flow management system **606**) disposed in the build chamber **200** can be configured to monitor the pressure of the build chamber **200** regularly at a user-define time period when the additive manufacturing system is activated. If the pressure inside the build chamber **200** rises or drops with regards to the target-pressure, the DGF system **600**, via the processor **106**, can be configured to use the gas inlets **602** and the gas outlets **608** to change the pressure inside the build chamber **200** to the target-pressure defined by the user. In some embodiments of the DGF system **600**, the processor **106** is configured to display a rise or drop in pressure inside the build chamber **200** via a user-interactive interface. In other embodiments of the DGF system **600**, if the pressure drop or pressure increase in the build chamber is significant with regards to the target-pressure, the processor **106** is configured to do a repeated pressure reading with the pressure sensor inside the build chamber **200** and turning the additive manufacturing system **100** off if the pressure rise or drop cannot be adjusted to the target-pressure defined by the user.

[0134] In some embodiments of the DGF system **600**, adjustment of the gas flow can be dependent on where the laser **502** is configured to work in the build chamber **200**. For example, in the embodiment of the DGF system **600** of FIG. **6**A, the DGF system **600** can adjust the gas flow toward that area in the build chamber **200** to remove particulates created by the irradiation device when the laser **502** is working on manufacturing the part in one corner of the build chamber **200**. In some embodiments of the DGF system **600**, the gas flow management system **606** of the DGF system can be configured to include a controller (not shown in FIG. **6**A) that is in communication with the processor and is configured to contain the steps for creating the part and knowing what location the laser **502** will be working at any given time. In some embodiments, the controller can also be contain information on how long it will take for the gas flow to adjust and re-establish the target gas flow conditions depending on which or how many gas inlets **602** and gas outlets **608** are being utilized simultaneously.

[0135] In some embodiments of the DGF system **600** shown in FIG. **6**A, the DGF system **600** can also redirect the gas flow during the recoating process when the laser **502** is not working to ensure optimal recoating without new material powder erosion caused by relatively accelerated gas flow and turbulent flow conditions. In some embodiments of the DGF system **600**, the DGF system **600** can reduce the gas flow in the vicinity of the recoater **410** during the recoating process such as by utilizing specific gas inlets **602** and gas outlets **608** to the build chamber **200**. In many embodiments of the DGF system **600**, adjustment of the gas flow can be achieved by controlling parameters, via the processor **106**, including power of the laser **502**, diameter of the laser **502**, time the laser **502** spends in particular working region, type of material powder, part being manufactured, and build time.

[0136] As described above, the appropriate embodiment of the DGF system **600** of FIG. **6**A is chosen as needed by the aspect of the additive manufacturing system **100**. Referring to FIGS. **6**B-**6**D, screenshots (**620**-**624**) of process screens of an exemplary simulation to determine the embodiment of the DGF system **600** is shown. In the screenshot **620** of FIG. **6**B, the geometric conditions of the simulation are established. In the screenshot **622** of FIG. **6**C, various parameters (e.g., volumetric flowrate, etc.) are considered in relation to the gas flow in the laser region of the build chamber **200** (actual parameter numbers have been replaced by placeholder values). In the screenshot **624** of FIG. **6**D, an exemplary mesh is generated by the simulation based on the parameters discussed in FIG. **6**C. In some embodiments of the simulation, the simulation process can be automated with software such as HEEDs.

[0137] Referring to FIG. **6**E, exemplary screenshots (**626** and **628**) of analysis by the simulation of the gas flow at multiple layers of the simulated build chamber **200** from FIG. **6**D are shown.

[0138] Referring to FIGS. **6**F-**1**-**6**F-**4**, exemplary screenshots (**652**-**658**) of the outputs of the simulation presenting an optimized embodiment of the DGF system **600** are shown. FIGS. **6**F-**1**-**6**F-**3** present exemplary screenshots (**652**-**656**) with exemplary schematic of an optimized embodiment of the DGF system **600** which include location of placement of the bypass gas inlet **610**, optimization of the hole sizes and hole spacing of the bypass gas inlet **610**. Using optimized hole sizes and hole spacing as determined by simulations of various flow conditions provides improved functionality of the DGF system **600**. FIG. **6**F-**4** presents an exemplary screenshot (**658**) of the 3D rendering and a mesh, respectively, based on the optimized embodiment of the DGF system **600**.

[0139] Referring to FIGS. **6**G-**1**-**6**G-**2**, perspective views of exemplary embodiments of the DGF system **600** are shown. In the embodiment of FIG. **6**G-**1**, the DGF system **600** includes the gas inlet **602** disposed on a side **662** of the build chamber **200** closer to a roof **664** of the build chamber **200**, and the gas outlet **608** disposed on the side **662** of the build chamber **200** closer to a floor **666** of the build chamber **200**. In the embodiment of FIG. **6**G-**2**, the DGF system **600** includes the gas inlet **602** disposed on a side **662** of the build chamber **200** closer to the roof **664** of the build chamber, and the gas outlet **608** disposed near the front of the floor **666** of the build chamber **200**. The embodiment of the DGF system **600** in FIG. **6**G-**2** further includes the bypass gas inlet **610**.

[0140] Referring to FIGS. **6**H-**1**-**6**H-**2**, exemplary screenshots (**668**-**670**) of analysis by the simulation of the gas flow by embodiments of the DGF system **600** of FIG. **6**G-**1** with a lower gas inlet **602** and an upper gas inlet **602** are shown respectively.

[0141] Referring to FIG. **6**H-**3**, an exemplary screenshot (**672**) of analysis by the simulation of the gas flow from a top view by an embodiment of the DGF system **600** is shown.

[0142] Referring to FIGS. **6**I-**1**-**6**I-**2**, exemplary screenshots (**674**-**676**) of analysis by the simulation of the gas flow by embodiments of the DGF system **600** of FIG. **6**G-**2** with a gas flow only into a lower gas inlet **602** are shown respectively.

[0143] Referring to FIGS. **6**I-**3**-**6**I-**4**, exemplary screenshots (**678**-**680**) of analysis by the simulation of the gas flow by embodiments of the DGF system **600** of FIG. **6**G-**2** with a gas flow only into an upper gas inlet **602** are shown respectively.

[0144] Referring to FIGS. **6**I-**5**-**6**I-**6**, exemplary screenshots (**682**-**684**) of analysis by the simulation of the gas flow by embodiments of the DGF system **600** of FIG. **6**G-**2** with gas flow into an upper gas inlet **602** and the bypass gas inlet **602** are shown respectively.

[0145] Referring to FIGS. **6**J-**1**-**6**J-**2**, exemplary screenshots (**686**-**688**) of analysis by the simulation of the gas flow by an embodiment of the DGF system **600** of FIG. **6**G-**1** and an embodiment of the DGF system **600** of FIG. **6**G-**2** are shown respectively.

[0146] Referring to FIGS. **6**J-**3**-**6**J-**4**, exemplary screenshots (**690**-**692**) of analysis by the simulation of the gas flow by two different embodiments of the DGF system **600** of FIG. **6**G-**2** are shown respectively. In the two different embodiments of the DGF system **600** include a curved baffle (not shown in figures) with a different shape.

[0147] Referring to FIGS. **6**J-**5**-**6**J-**6**, exemplary screenshots (**694**-**696**) of comparison rendering output by the simulation of the gas flow by an embodiment of the DGF system **600** of FIG. **6**G-**1** and an embodiment of the DGF system **600** of FIG. **6**G-**2** are shown respectively.

[0148] The DGF system **600** for the additive manufacturing system **100** can utilize and combine features from any of the embodiments and aspects discussed above.

[0149] A reference to an element in the singular is not intended to mean one and only one unless specifically so stated, but rather one or more. For example, "a" module may refer to one or more modules. An element proceeded by "a," "an," "the," or "said" does not, without further constraints, preclude the existence of additional same elements.

[0150] Phrases such as an aspect, the aspect, another aspect, some aspects, one or more aspects, an implementation, the implementation, another implementation, some implementations, one or more implementations, an embodiment, the embodiment, another embodiment, some embodiments, one or more embodiments, a configuration, the configuration, another configuration, some configurations, one or more configurations, the subject technology, the disclosure, the present disclosure, other variations thereof and alike are for convenience and do not imply that a disclosure relating to such phrase(s) is essential to the subject technology or that such disclosure applies to all configurations of the subject technology. A disclosure relating to such phrase(s) may apply to all configurations, or one or more configurations. A disclosure relating to such phrase (s) may provide one or more examples. A phrase such as an aspect or some aspects may refer to one or more aspects and vice versa, and this applies similarly to other foregoing phrases.

[0151] It is understood that the specific order or hierarchy of steps, operations, or processes disclosed is an illustration of exemplary approaches. Unless explicitly stated otherwise, it is understood that the specific order or hierarchy of steps, operations, or processes may be performed in different order. Some of the steps, operations, or processes may be performed simultaneously. The accompanying method claims, if any, present elements of the various steps, operations or processes in a sample order, and are not meant to be limited to the specific order or hierarchy presented. These may be performed in serial, linearly, in parallel or in different order. It may be understood that the described instructions, operations, and systems can generally be integrated together in a single software/hardware product or packaged into multiple software/hardware products.

[0152] The disclosure is provided to enable any person skilled in the art to practice the various aspects described herein. In some instances, well-known structures and components are shown in block diagram form in order to avoid obscuring the concepts of the subject technology. The disclosure provides various examples of the subject technology, and the subject technology is not limited to these examples. Various modifications to these aspects will be readily apparent to those skilled in the art, and the principles described herein may be applied to other aspects.

[0153] All structural and functional equivalents to the elements of the various aspects described throughout the disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims.

[0154] The various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention.

[0155] The hardware used to implement the various illustrative logics, logical blocks, modules, and circuits described in connection with the aspects disclosed herein may be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general-purpose processor may be a microprocessor, but, in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. Alternatively, some steps or methods may be performed by circuitry that is specific to a given function.

[0156] In one or more exemplary aspects, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored as one or more instructions or code on a non-transitory computer-readable medium or non-transitory processor-readable medium. The steps of a method or algorithm disclosed herein may be embodied in a processor-executable software module which may reside on a non-transitory computer-readable or processor-readable storage medium. Non-transitory computer-readable or processor-readable storage media may be any storage media that may be accessed by a computer or a processor. By way of example but not limitation, such non-transitory computer-readable or processor-readable media may include RAM, ROM, EEPROM, FLASH memory, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that may be used to store desired program code in the form of instructions or data structures and that may be accessed by a computer. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk, and Blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above are also included within the scope of non-transitory computer-readable and processor-readable media. Additionally, the operations of a method or algorithm may reside as one or any combination or set of codes and/or instructions on a non-transitory processor-readable medium and/or computer-readable medium, which may be incorporated into a computer program product.

[0157] The title, background, brief description of the drawings, abstract, and drawings are hereby incorporated into the disclosure and are provided as illustrative examples of the disclosure, not as restrictive descriptions. It is submitted with the understanding that they will not be used to limit the scope or meaning of the claims. In addition, in the detailed description, it can be seen that the description provides illustrative examples and the various features are grouped together in various implementations for the purpose of streamlining the disclosure. The method of disclosure is not to be interpreted as reflecting an intention that the claimed subject matter requires more features than are expressly recited in each claim.

What is claimed is:

1. An additive manufacturing system for manufacturing a component, the additive manufacturing system comprising:
- a frame;
- an additive manufacturing machine disposed on the frame, the additive manufacturing machine comprising:
  - a Z-axis levelling system comprising a build platform for manufacturing the component, the Z-axis levelling system configured to adjust a height of the build platform;
  - a build chamber configured to accommodate the build platform;
  - a powder delivery system, the powder delivery system configured to deliver the material powder to the build platform;
  - an adaptive laser beam control system disposed inside the build chamber, the adaptive laser beam control system comprising at least one laser for irradiating the material powder on the build platform; and
  - a dynamic gas flow system disposed on the build chamber, the dynamic gas flow system configured to:
    - deliver and regulate a flow of gas in and out of the build chamber; and
    - remove, from the build chamber, particulates created during the irradiation of the material powder by the at least one laser;
- a processor electronically coupled to the additive manufacturing machine, the processor configured to control the additive manufacturing machine, wherein the pro-

cessor is configured to automatically pressurize the build chamber to a user-determined pressure threshold value via controlling the dynamic gas flow system; and

a memory unit coupled to the processor, the memory unit comprising stored instructions for controlling the additive manufacturing machine via the processor.

2. The additive manufacturing system of claim 1, wherein the build chamber comprises:

a housing comprising at least four walls, wherein each of the at least four walls are configured to have an interior wall surface;

a build platform opening on the housing, the build platform opening configured to accommodate the build platform; and

a door disposed on one of the at least four walls of the build chamber, configured to give a user access to the build chamber.

3. The additive manufacturing system of claim 2, wherein the build chamber further comprises:

a roof disposed on the housing;

a floor disposed on the housing, the floor configured to include the build platform opening;

at least one inlet disposed on the housing; and

at least one outlet disposed on the housing, wherein the at least one inlet and the at least one outlet are configured for movement of gas facilitated via the dynamic gas flow system.

4. The additive manufacturing system of claim 3, wherein the build chamber further includes a viewing window for a user to view the manufacturing of the component by the additive manufacturing system.

5. The additive manufacturing system of claim 3, wherein the build chamber further includes a powder delivery system opening configured to allow the powder delivery system to deliver the material powder to the build platform.

6. The additive manufacturing system of claim 1, wherein the build chamber comprises a plurality of sensors configured to:

monitor environmental conditions in the build chamber; and

transmit feedback data of the environmental conditions to the processor.

7. The additive manufacturing system of claim 6, wherein the environmental conditions is selected from a group including temperature, oxygen level, and pressure of the build chamber.

8. The additive manufacturing system of claim 7, wherein the plurality of sensors includes at least one of a pressure sensor configured to measure the pressure of the build chamber.

9. The additive manufacturing system of claim 8, wherein the processor is configured to control the dynamic gas flow system to pressurize the build chamber with the steps including:

pump in an inert gas into the build chamber via a gas inlet of the dynamic gas flow system; and

pump out oxygen gas out of the build chamber via a gas outlet of the dynamic gas flow system.

10. The additive manufacturing system of claim 9, wherein the inert gas is argon gas.

11. A method of manufacturing a component with an additive manufacturing system, the method comprising the steps of:

(a) providing the additive manufacturing system comprising:

a frame;

an additive manufacturing machine disposed on the frame, the additive manufacturing machine comprising:

a Z-axis levelling system comprising a build platform for manufacturing the component;

a build chamber configured to accommodate the build platform;

a powder delivery system;

an adaptive laser beam control system disposed inside the build chamber;

a dynamic gas flow system;

a processor electronically coupled to the additive manufacturing machine, the processor configured to control the additive manufacturing machine, wherein the processor is configured to automatically pressurize the build chamber to a user-determined pressure threshold value via controlling the dynamic gas flow system; and

a memory unit coupled to the processor, the memory unit comprising stored instructions for controlling the additive manufacturing machine via the processor.

(b) adjusting the height of the build platform with the Z-axis leveling system;

(c) delivering a dose of the material powder to the build platform via the powder delivery system, wherein the dose of the material powder corresponds to one layer of a plurality of layers of the component to be manufactured;

(d) irradiating the material powder with the at least one laser of the adaptive laser beam control system, wherein the dynamic gas flow system, during the irradiation of the material powder, is configured to deliver and regulate a flow of gas in and out of the build chamber; and remove, from the build chamber, particulates created during the irradiation of the material powder by the at least one laser; and

(e) repeating steps (b) to (d) until the plurality of layers of the component to be manufactured are manufactured.

12. The method of claim 11, wherein the build chamber of the additive manufacturing system comprises:

a housing comprising at least four walls, wherein each of the at least four walls are configured to have an interior wall surface;

a build platform opening on the housing, the build platform opening configured to accommodate the build platform; and

a door disposed on one of the at least four walls of the build chamber, configured to give a user access to the build chamber.

13. The method of claim 12, wherein the build chamber further comprises:

a roof disposed on the housing;

a floor disposed on the housing, the floor configured to include the build platform opening;

at least one inlet disposed on the housing; and

at least one outlet disposed on the housing, wherein the at least one inlet and the at least one outlet are configured for movement of gas facilitated via the dynamic gas flow system.

14. The method of claim **13**, wherein the build chamber further includes a viewing window for a user to view the manufacturing of the component by the additive manufacturing system.

15. The method of claim **13**, the build chamber further includes a powder delivery system opening configured to allow the powder delivery system to deliver the material powder to the build platform.

16. The method of claim **11**, wherein the build chamber comprises a plurality of sensors configured to:

monitor environmental conditions in the build chamber; and

transmit feedback data of the environmental conditions to the processor.

17. The method of claim **16**, wherein the environmental conditions is selected from a group including temperature, oxygen level, and pressure of the build chamber.

18. The method of claim **17**, wherein the plurality of sensors includes at least one of a pressure sensor configured to measure the pressure of the build chamber.

19. The method of claim **18**, wherein the processor is configured to control the dynamic gas flow system to pressurize the build chamber with the steps including:

pump in an inert gas into the build chamber via a gas inlet of the dynamic gas flow system; and

pump out oxygen gas out of the build chamber via a gas outlet of the dynamic gas flow system.

20. The method of claim **19**, wherein the inert gas is argon gas.

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