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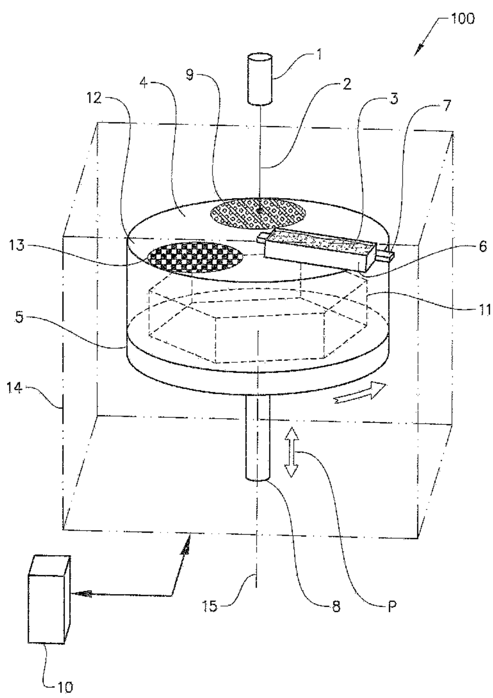

FIG. 1

(57) Abstract: A method for forming at least one three-dimensional article through successive fusion of parts of a powder bed, which parts correspond to successive portions of the three- dimensional article, said method comprising the steps of: providing at least one model of said three-dimensional article, wherein said model of said three-dimensional article is described in a 2-dimensional angular coordinate system; applying a powder layer on a support structure; directing at least one energy beam from at least one energy beam source over said powder layer causing said powder layer to fuse in first selected locations according to said model to form a first portion of said three-dimensional article, providing a first portion of said powder layer simultaneous as fusing a second portion of said powder layer, wherein said second portion of the powder layer is fused along a line perpendicular to a rotational axis of said support structure.

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METHOD AND APPARATUS FOR ADDITIVE MANUFACTURING USING A TWO DIMENSIONAL ANGULAR COORDINATE SYSTEM

BACKGROUND

Technical Field

[0001] The present invention relates to an improved method for manufacturing a 3-dimensional object.

Related Art

[0002] Freeform fabrication or additive manufacturing is a method for forming three-dimensional articles through successive fusion of chosen parts of powder layers applied to a work plate. A method and apparatus according to this technique is disclosed in US 2009/0152771.

[0003] Such an apparatus may comprise a work plate 5 on which the three-dimensional article is to be formed, a powder dispenser, arranged to lay down a thin layer of powder on the work plate 5 for the formation of a powder bed, a ray gun for delivering energy to the powder whereby fusion of the powder takes place, elements for control of the ray given off by the ray gun over the powder bed for the formation of a cross section of the three-dimensional article through fusion of parts of the powder bed, and a controlling computer, in which information is stored concerning consecutive cross sections of the three-dimensional article. A three-dimensional article is formed through consecutive fusions of consecutively formed cross sections of powder layers, successively laid down by the powder dispenser.

[0004] Sliced files are widely used for additive manufacturing applications and can be generated using digital data, such as any suitable solid computer aided design ("CAD") model. The sliced layers consist of successive cross-sections taken at ascending Z-intervals where each slice is taken parallel to the XY-plane as shown in Figure 3, with Z along a vertical direction. Usually, a sliced file is generated to get a full representation of three-dimensional model consisting of the superposition of successive cross-sections. According to this usual slicing algorithm, all layers are considered separately and even if several consecutive layers are similar, their coding size remains approximately the same leading to a huge file which may be a problem.

[0005] There is a demand for additive manufacturing techniques which is capable of building three-dimensional articles faster and faster. This may ultimately require an additive manufacturing method in which the current slicing method is more or less unsuitable.

BRIEF SUMMARY

[0006] An object of the present invention is to provide a slicing method which is suitable for continuous additive manufacturing of three-dimensional parts.

[0007] In a first aspect according to various embodiments of the invention it is provided a method for forming at least one three-dimensional article through successive fusion of parts of a powder bed, which parts correspond to successive portions of the three-dimensional article. The method comprising the steps of: providing at least one model of the three-dimensional article, wherein the model of the three-dimensional article is described in a 2-dimensional angular coordinate system; applying a powder layer on a support structure; directing at least one energy beam from at least one energy beam source, the energy beam source being an electromagnetic energy beam source and/or a charged particle beam source, over the powder layer causing the powder layer to fuse in first selected locations according to the model to form a first portion of the three-dimensional article, providing a first portion of the powder layer simultaneous as fusing a second portion of the powder layer, wherein the second portion of the powder layer is fused along a line perpendicular to a rotational axis of the support structure.

[0008] An exemplary advantage of various embodiments of this invention is that the description of the three-dimensional article eliminates one dimension, thus allowing to associate an angular position to the article's boundaries along a radial line. This allows for a continuous operation of an additive manufacturing process, i.e., transforming the usual step-by-step slicing description and the step-by-step manufacturing process of the 3-d object into a continuous slicing description and a continuous movement where the melting step can be uninterrupted leading to a better thermal handling and higher productivity level.

[0009] In various example embodiments according to the present invention a single beam is scanning along the line perpendicular to the rotational axis. An exemplary advantage of at least these embodiments is that a single energy beam source is needed which only requires to have the capability of being deflected in a 1-dimensional direction.

[0010] In various example embodiments of the present invention a plurality of beams are melting along the line perpendicular to the rotational axis simultaneously. An exemplary advantage of at least these embodiments is that one or a plurality of the beam may not need to possess any deflection capability. Some or all of the beam may be stationary, i.e., pointing at one specific point only. A longer line may require a larger numbers of beams.

[0011] In various example embodiments according to the present invention the rotational axis is along the Z-axis and the at least one beam is fusing essentially in an XY-plane. An exemplary advantage of at least these embodiments is that the line may be chosen to be fused at a numerous places at the XY-plane.

[0012] In various example embodiments of the present invention, the method further comprising the step of moving the support structure in z-direction at a predetermined speed while rotating the support structure at a predetermined speed. An exemplary advantage of at least these embodiments is that the rotation speed and/or the movement speed along the Z-axis may be fixed or altered during the manufacture of a three-dimensional article. The rotational speed and the movement speed of the support structure along the Z-axis may be synchronized with the 2-dimensional description of the three-dimensional article so that the slicing thickness in the 2-dimensional description of the 3-dimensional model represents the actual powder layer thickness that is to be fused.

[0013] In various example embodiments the support structure is a horizontal plate. The plate may be of any shape such as circular, rectangular or polygon shaped. The plate may be made of the same or different material as the powder material as used for building the 3-dimensional article. An exemplary advantage of at least these embodiments is that the plate may be part of the final three-dimensional article.

[0014] In various example embodiments the energy beam may be provided off axis with respect to the rotational axis of the support structure. An exemplary advantage of at least these embodiments is that a larger area may be covered compared to if an optical axis of the energy beam source are aligned to the rotational axis.

[0015] In various example embodiments of the present invention, the rotational axis of the support structure is essentially horizontal and wherein the second portion of the powder layer is fused along a line in parallel to a rotational axis of the support structure instead of perpendicular to the rotational axis.

[0016] In this example embodiment the 3-dimensional article is growing in a radial direction. An exemplary advantage of at least these embodiments is that the support structure may be a pre manufactured part which is to be repaired, such as a turbine or compressor wheel which is damaged in the outer parts of one or a plurality of its blades.

[0017] In various example embodiments of the present invention a single beam is scanning along the line parallel to the rotational axis of the support structure. An exemplary advantage of at least these embodiments is that a single energy beam source is needed which only requires to have the capability of being deflected in a 1-dimensional direction.

[0018] In various example embodiments of the present invention a plurality of beams are melting the line parallel to the rotational axis of the support structure simultaneously. An exemplary advantage of at least these embodiments is that one or a plurality of the beam may not need to possess any deflection capability. Some or all of the beam may be stationary, i.e., pointing at one specific point at the support structure only. A longer line may require a larger numbers of beams.

[0019] In various example embodiments of the present invention, the line perpendicular to the rotational axis, where the rotational axis is vertical or horizontal, is a straight line or a meandering line resulting in a straight fusion zone or a meandering fusion zone. An exemplary advantage of at least these embodiments is that a shape of the fusion zone may be manipulated by letting the deflection of the energy beam deflect in a straight or non-straight direction or letting the plurality of energy beams forming a straight fusion zone or a non-straight fusion zone.

[0020] In various example embodiments of the present invention the support structure is a cylinder with a radius, which radius is increasing in length from a first to a second layer proportional to an applied powder layer thickness. An exemplary advantage of at least these embodiments is that rotational speed of the support structure may be synchronized with the 2-dimensional description of the three-dimensional article so that the slicing thickness in the 2-dimensional description of the 3-dimensional model represents the actual powder layer thickness which is to be fused.

[0021] In various example embodiments of the present invention a rotational axis of the model is coinciding with the rotational axis of the three-dimensional article built on the support structure. An exemplary advantage of at least these embodiments is that the slicing description and the actual build of the three-dimensional article may be easily synchronized with each other.

[0022] In various example embodiments of the present invention the powder layer is provided continuously on the support structure during the formation of the three-dimensional article. An exemplary advantage of at least these embodiments is that there is no interruption of the powder supply during the complete build of the 3-dimensional article, which may simplify the design of the powder application equipment.

[0023] In various example embodiments of the present invention the support structure is rotating clockwise or anticlockwise during the formation of the three-dimensional article. An exemplary advantage of at least these embodiments is that the rotational direction is the same during the complete manufacture of a three-dimensional article which still further simplify the design of the additive manufacturing apparatus as well as reducing risk of introducing synchronization and/or accuracy errors due to the fact that the rotational direction is changed.

[0024] In various example embodiments of the present invention further comprising the step of preheating a third portion of the powder layer. An exemplary advantage of at least these embodiments is that the fusing may take place on a powder surface having the correct temperature and/or properties for achieving the desired material characteristics. Another exemplary advantage is that the preheating may take place simultaneously as the fusing but on a different area compared to the fusing area.

[0025] In various example embodiments of the present invention the preheating may be performed by using at least one of the energy sources used for fusing the powder layer or any alternative energy beam source. An exemplary advantage of at least these embodiments is that it is possible to use the same and/or another energy beam source for the preheating, i.e., the step taken place before the actual fusion step, then the energy source used for the actual fusion. The preheating energy source may be of the same type or of another type. The preheating source may in an example embodiment heat the entire surface of the powder layer on the support structure. In an example embodiment the source used for preheating may be multiple sources used in sequence or in parallel with each other.

[0026] According to another aspect of various embodiments, there is provided a program element configured and arranged when executed on a computer to implement a method for forming at least one three-dimensional article through successive fusion of parts of a powder bed, which parts correspond to successive portions of the three-dimensional article, the method comprising the step of: providing at least one model of the three-dimensional article, wherein the model of the three-dimensional article is described in a two-dimensional angular coordinate system; applying a powder layer on a support structure; directing at least one energy beam from at least one energy beam source, the energy beam source being at least one of an electromagnetic energy beam source or a charged particle beam source, over the powder layer causing the powder layer to fuse in first selected locations according to the model to form a first portion of the three-dimensional article, providing a first portion of the powder layer simultaneous as fusing a second portion of the powder layer, wherein the second portion of the powder layer is fused along a line perpendicular to a rotational axis of the support structure.

[0027] According to various embodiments, a non-transitory computer readable medium is provided, having stored thereon the program element.

[0028] According to yet another aspect of various embodiments, a computer program product is provided, comprising at least one non-transitory computer-readable storage medium having computer-readable program code portions embodied therein. The computer-readable program code portions comprise: an executable portion configured for, upon receipt of at least one model of the three-dimensional article, wherein the model of the three-dimensional article is described in a two-dimensional angular coordinate system, applying a powder layer on a support structure; an executable portion configured for directing at least one energy beam from at least one energy beam source, the energy beam source being at least one of an electromagnetic energy beam source or a charged particle beam source, over the powder layer causing the powder layer to fuse in first selected locations according to the model to form a first portion of the three-dimensional article; and an executable portion configured for providing a first portion of the powder layer simultaneous as fusing a second portion of the powder layer, wherein the second portion of the powder layer is fused along a line perpendicular to a rotational axis of the support structure.

[0029] According to yet another aspect of various embodiments, there is provided an apparatus for forming a three-dimensional article through successive fusion of parts of a powder bed, which parts corresponds to successive cross sections of the three-dimensional article. The apparatus comprises: a control unit having stored thereon a computer model of the three-dimensional article; at least one energy beam from at least one energy beam source, the energy beam source being at least one of an electromagnetic energy beam source or a charged particle beam source, the at least one energy beam being configured to be directed, via the control unit, over the powder layer so as to cause the powder layer to fuse in first selected locations according to the model to form a first portion of the three-dimensional article; a rotational support structure, wherein the rotation of the rotational support structure occurs about a rotational axis of the support structure, such that a second portion of the powder layer is fused along a line perpendicular to the rotational axis simultaneous with the formation of the first portion.

[0030] Herein and throughout, where an exemplary embodiment is described or an advantage thereof is identified, such are considered and intended as exemplary and non-limiting in nature, so as to not otherwise limit or constrain the scope and nature of the inventive concepts disclosed.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

[0031] The invention will be further described in the following, in a non-limiting way with reference to the accompanying drawings. Same characters of reference are employed to indicate corresponding similar parts throughout the several figures of the drawings:

[0032] Figure 1 presents an example embodiment of an arrangement where a rotating work plate 5 is lowered continuously and simultaneously each revolution by mean of an elevator mechanism that incorporates a rotation axis.;

[0033] Figure 2 shows a top view of an example embodiment of the present invention in the case where the build envelope 11 is about three times the beam scanning area 9;

[0034] Figure 3 depicts a slicing method of a 3-d hollow cylinder according to prior art;

[0035] Figure 4 depicts a slicing method of a 3-d hollow cylinder according to the present invention;

[0036] Figures 5A-5B depict an example embodiment of a 3-dimensional object which is sliced according to Figure 4 and described in a 2-dimensional coordinate system according to the present invention;

[0037] Figure 6 depicts a first example embodiment of the present invention in which a 3-dimensional article is sliced along Z-axis continuously both with respect to rotation and translation;

[0038] Figure 7 depicts a second example embodiment of the present invention in which the same 3-dimensional article as illustrated in Figure 6 is sliced along a radius continuously both with respect to rotation and translation;

[0039] Figure 8 depicts schematically a flow chart of an example embodiment of the present invention;

[0040] Figure 9 is a block diagram of an exemplary system **1020** according to various embodiments;

[0041] Figure 10A is a schematic block diagram of a server **1200** according to various embodiments; and

[0042] Figure 10B is a schematic block diagram of an exemplary mobile device **1300** according to various embodiments.

DETAILED DESCRIPTION OF VARIOUS EMBODIMENTS

[0043] Various example embodiments of the present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the invention are shown. Indeed, embodiments of the invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly known and understood by one of ordinary skill in the art to which the invention relates. The term "or" is used herein in both the alternative and conjunctive sense, unless otherwise indicated. Like numbers refer to like elements throughout.

[0044] To facilitate the understanding of this invention, a number of terms are defined below. Terms defined herein have meanings as commonly understood by a person of ordinary skill in the areas relevant to the present invention. Terms such as "a", "an" and "the" are not intended to refer to only a singular entity, but include the general class of which a specific example may be used for illustration. The terminology herein is used to describe specific embodiments of the invention, but their usage does not delimit the invention, except as outlined in the claims.

[0045] The term "three-dimensional structures" and the like as used herein refer generally to intended or actually fabricated three-dimensional configurations (e.g. of structural material or materials) that are intended to be used for a particular purpose. Such structures, etc. may, for example, be designed with the aid of a three-dimensional CAD system.

[0046] The term “electron beam” as used herein in various embodiments refers to any charged particle beam. The sources of a charged particle beam can include an electron gun, a linear accelerator and so on.

[0047] The invention relates to a method for producing three-dimensional objects by powder additive manufacturing, for example by selective laser melting (SLM), selective laser sintering (SLS) or Electron Beam Melting (EBM). In various example embodiments the object may be wider than the beam scanning area.

[0048] An energy beam source 1 may be used so that a beam 2 defines a 2D pattern in a thin bed of metal powder material 3 leveled by rake 6. The rake may be movable or stationary. A powder bed 4 may in an example embodiment measure a diameter 750 mm in a plan view and a work plate 5 can be lowered 200-500 mm by a mechanism elevator 8. Thus parts up to ∅ 750 x 500 mm can be manufactured in such equipment. It should be understood that these are not fundamental limits however.

[0049] Sliced files are widely used for additive manufacturing applications and can be generated using digital data, such as any suitable solid computer aided design (“CAD”) model. The sliced layers may consist of successive cross sections taken at ascending Z-intervals, where each slice is taken parallel to the XY plane as shown on FIG. 3, with Z along a vertical direction.

[0050] To allow additive manufacturing to be conducted in a continuous way, a continuous computer description of a 3D object may be used. Such continuous description may eliminate one dimension, thus allowing to associate an angular position to the object’s boundaries along a radial line.

[0051] A possible application of this invention may consist in adjusting dynamically the position of a printer head - or a beam spot - along a radial line to melt the 3D object between the 1D segments described in this mathematical representation. With an appropriate system coordinate change, each interior and exterior boundary polyline from the solid material can advantageously be described in the two dimensional coordinate system (r ,α) as follow:

[0052] $r = \sqrt{x^2 + y^2}$; $\alpha =(\frac{2\pi}{z})*H$

[0053] where (x,y,z) are the Cartesian coordinates, r is a radial coordinate (distance to Z axis) and α is an angular coordinate [rad]. α is positive if measured counter clockwise as seen from any point with positive height. H is the height of the three-dimensional article which is to be built.

[0054] According to the method proposed by the present invention, a mathematical model may be generated from a helical like cutting of a three-dimensional article to be formed as shown in Figure 4. This slicing method require to define a rotation axis along for instance Z (longitudinal) and an origin angular position.

[0055] A file containing all r coordinates (intersecting the line that rotates uniformly around the axis) can be generated for each angular coordinate α with a step size chose in accordance to the accuracy needed. For instance, a three-dimensional article resulting from the Boolean union between: i) a cylindrical tube with the height of 100 mm and of internal radius 300 mm and external radius 301 mm ; with, ii) a conical frustum with the height 100 mm and upper internal and external radii 300 mm and 301 mm respectively and bottom internal and external radii 319 mm and 320 mm respectively; with, iii) a triangular flange with the height 100 mm and base 20 mm and a thickness of 1 mm placed between i) and ii) ; may be described, according to the inventive method, by a continuous helical cutting as shown on Figure 5A and Figure 5B.

[0056] The digital representation of the 3D object may result in better accuracy if the slice thickness is chosen accordingly to the minimal details accuracy.

[0057] In the previously mentioned example, the result of the coarse helical-like slicing along the Z-axis parallel to length L, with a slice thickness t=20 mm is defined in this system coordinate as presented as a graph in the FIG. 5. In this simple test-case a full description of the 3D object is obtained in 5 laps (part height divided by t).

[0058] The full representation of such a three-dimensional model would correspond to a very minimal coding size, in the previously mentioned example the digital data to store to construct the closed segment lines consist in 32 points only being in the two dimensional coordinate system (r ,z):

Boundary loop (1)=300,0;300,100;301,100;320,0;319,0;317.1,10;301.1,10;301,0;300,0 ;

Boundary loop (2)=301,11;301,30;313.3,30;316.9,11;301,11 ;

Boundary loop (3)=301,31;301,50;309.5,50;313.1,31;301,31 ;

Boundary loop (4)=301,51;301,70;305.7,70;309.3,51;301,51 ;

Boundary loop (5)=301,71;301,90;301.9,90;305.5,71;301,71 ;

Boundary loop (6)=301,91;301,94.7;301.7,91

[0059] Figure 1 discloses only one beam source for sake of simplicity. Of course, any number of beam sources may be used.

[0060] In the embodiment of this invention illustrated in Figure 1, the work plate 5 can be moved in a process chamber 14across a beam scan area 9 such that:

[0061] a) a continuous cutting model (continuous slicing) of the article to build is generated and stored in the control unit 10.

[0062] b) an optional preheating a work plate 5 to an adequate start temperature. Energy deposition on the work plate 5 during preheating may be done either during an incremental or continuous movement of the work plate 5.

[0063] c) depositing with a moving feeding member of a quantity of powder in the melting chamber to form a layer of powders with a regular and substantially uniform thickness. This may be done, but not limited to, by a fixed powder layering device while the work plate 5 is moving.

[0064] d) an optional preheating the layer of powder to a temperature below the melting point of the powders. The energy may be transmitted to the powders either during an incremental or continuous work plate 5 movement. As a function of the temperature loss during one rotation, it is possible to arrange a reheat area 12 before the powder come again to the beam scan area.

[0065] e) performing the melting by scanning with a focused beam in the area corresponding to a portion of the continuous cutting of the article according to the model stored in the control unit 10.

[0066] Repeating the steps b) to e) occurs either as the work plate 5 rotates continuously either incrementally with a “quadrant” rotation until reaching the top definition of the article. The work plate 5 is lowered as the build progress, each revolution a distance ranging 20 to 200 µm equal to the thickness of the completed layer.

[0067] The vacuum chamber 320 is capable of maintaining a vacuum environment by means of or via a vacuum system, which system may comprise a turbo molecular pump, a scroll pump, an ion pump and one or more valves which are well known to a skilled person in the art and therefore need no further explanation in this context. The vacuum system may be controlled by the control unit 10. In another embodiment the work plate may be provided in an enclosable chamber provided with ambient air and atmosphere pressure. In still another example embodiment the work plate may be provided in open air.

[0068] This invention concerns the provision of a rotation axis to the work plate 5 aligned or non-aligned with the center line of the energy beam. In an example embodiment of the present invention the axis of rotation 15 may be vertical and the work plate 5 may be annular. This rotation can be done intermittently or continuously together with the work plate 5 lowering continuously as the build progress.

[0069] By this mean, in the case of an energy beam non-aligned with the rotational axis 15, the build envelope can be much wider than the beam scan area in a powder bed plan. It is obvious that the work plate 5 lowering range remain identical to standard equipment. It is entirely conceivable that the build envelope in vertical direction will be designed to extend the maximum build height up to approximately 1000 mm.

[0070] As illustrated in Figure 2, a three-dimensional object 11, in a rotational movement around an axis 15, is melted between its inner and outer boundary radii in the beam scanning area 9. The beam movement is coordinated with the rotational movement by the control unit 10. In this embodiment the melting strategy allow changing the revolution speed during the revolution of the work plate 5 and the melting is preferably located along the main radius between sector I and II. In this example, by use of a beam multiplexing, we get three concurrent spots 1, 2, 3 to produce several melted lines 16 (In this example, three lines along radii R1… R3). To simplify the multiplexing algorithm, the duration of each spot and frequency on each line is the same, at a given time of the building. The spots may emanate from a single source or from multiple sources. The sources may be of the same type or of different types.

[0071] At a given radius Ri, the relation between the angular speed ω and linear speed of the rotating powder bed is the following: *LineSpeed= Ri * ω (1)*

[0072] And we also have: *LineSpeed= SpotOffset * Fb / NbOfSpots (2)*

[0073] With: *NbOfSpots = (Rout - Rin) / Line offset (3)* where, - Spot Offset: distance between two successive melting spots on the same radius - Line Offset: distance between two adjacent lines - Line speed: speed of a powder particle - Fb: Beam pulse frequency

[0074] Thus, if we use a fixed value of Line Offset for an entire build cycle, the number of spots required to melt effectively the part geometry can change periodically according to eq. (3). Then taken into account a limit value for Spot Offset, the rotation speed may be calculated from the combination of eq. (1) and (2), at a given radius, in the middle for instance. Lastly, the linear speed difference of powder particles between the outer and inner radius can be accommodated by a change in beam power giving a homogeneous melting all along a radial line.

[0075] In Figure 2, sector I may be the preferred working area when multiplexing the beam on a radial line and other sectors II-IV are used to make easier any change in rotation speed. This arrangement eliminates the need of a XY-beam trajectory software and allow the machine to operate continuously in a 1-dimensional radial beam movement directly linked to the powder bed rotation speed.

[0076] The process may be particularly suitable to be applied to produce principally large parts, although not exclusively, turbine cases or large aerospace structural frames with a central hole. The present invention may be used for manufacturing one continuous object wider than the beam scanning area, it must be understood that the principles of the present invention can be applied equally to the production of several objects included into the build envelope.

[0077] It must be understood that the present invention is potentially applicable to any type of layer wise rapid prototyping and additive manufacturing machines, and to other machines using the layer-on-layer fabrication technique, including non-metallic material.

[0078] The energy beam source may be an electron beam source 1 generating an electron beam, which may be used for melting or fusing together powder material 3 provided on the work plate 5. The control unit 10 may be used for controlling and managing the electron beam 2 emitted from the electron beam source 1. The electron beam 2 may be deflected between at least a first extreme position and at least a second extreme position.

[0079] At least one focusing coil (not shown), at least one deflection coil (not shown) and an electron beam power supply (not shown) may be electrically connected to the control unit 10. A beam deflection unit (not shown) may comprise the at least one focusing coil, the at least one deflection coil and optionally at least one astigmatism coil. In an example embodiment of the invention the electron beam source 1 may generate a focusable electron beam with an accelerating voltage of about 60kV and with a beam power in the range of 0-3kW. The pressure in the vacuum chamber may be in the range of $1x10^{-3}$-$1x10^{-6}$ mBar when building the three-dimensional article by fusing the powder layer by layer with the energy beam source 1.

[0080] Instead of melting the powder material with one electron beam, one or more laser beams and/or electron beams may be used. Each laser beam may normally be deflected by one or more movable mirror provided in the laser beam path between the laser beam source and the work plate 5 onto which the powder material is arranged which is to be fused by the laser beam. The control unit 10 may manage the deflection of the mirrors so as to steer the laser beam to a predetermined position on the work plate 5.

[0081] The powder supply 6 may comprise the powder material to be provided on the work plate 5. The powder material may for instance be pure metals or metal alloys such as titanium, titanium alloys, aluminum, aluminum alloys, stainless steel, Co-Cr-W alloy, Ni-based alloys, Titanium aluminides, Niobium, silicon nitride, molybdenum disilicide and the like.

[0082] The powder distributor or powder feeding member 7 may be arranged to lay down a thin layer of the powder material on the work plate 5. During manufacturing of the three-dimensional article the work plate 5 will be continuously lowered and rotated in relation to the energy beam source. In order to make this movement possible, the work plate 5 may in one embodiment of the invention be arranged movably in vertical direction, i.e., in the direction indicated by arrow P. This means that the work plate 5 may start in an initial position, and continuously rotate around an axis 15 and move vertically along the axis 15. The work plate 5 may continuously be lowered and rotated while simultaneously providing new powder material for the formation of new cross sectional portions of the three-dimensional article. Means for lowering the work plate 5 may for instance be through a servo engine equipped with a gear, adjusting screws, and the like. The rotation may be performed with an electrical motor.

[0083] In Figure 8 it is depicted a flow chart of an example embodiment of a method according to the present invention. The method comprising a first step 810 of providing at least one model of the three-dimensional article. The models may be a computer model generated via a CAD (Computer Aided Design) tool. The three-dimensional articles which are to be built may be equal or different to each other.

[0084] In a second step 820 a first powder layer is applied on a support structure. The support structure may be a work plate 5. The work plate 5 may be a removable or fixed build platform, a powder bed, a partially fused powder bed or a pre-manufactured part. The powder may be distributed evenly over the work plate 5 according to several methods. One way to distribute the powder 3 is to let the powder material 3 in the powder supply 6 falling down onto the work plate 5. The powder supply may have an opening at its bottom facing the work plate 5, through which the powder may fall down to the work plate 5. A feeding member or rake 7 may ensure the powder material onto the work plate is provided uniformly to an essentially flat surface. The rake may be arranged stationary or movable.

[0085] A distance between a lower part of the rake 7 and the upper part of the work plate 5 or previous powder layer may determine the thickness of powder distributed over the work plate 5. The powder layer thickness can easily be adjusted by adjusting the distance between the lower part of the rake and the previous layer or the work plate 5.

[0086] In a third step 830 at least one energy beam is directing from at least one energy beam source, the energy beam source being an electromagnetic energy beam source and/or a charged particle beam source, over the powder layer causing the powder layer to fuse in first selected locations according to the model to form a first portion of the three-dimensional article.

[0087] The at least one energy beam may fuse the three-dimensional article with parallel scan lines so as to form a fusion zone extending in a direction perpendicular to an axis of rotation of the work plate 5.

[0088] The first energy beam may be an electron beam or a laser beam. The beam is directed over the work plate 5 from instructions given by the control unit 10. In the control unit 10 instructions for how to control the beam source 1 for each portions of the three-dimensional article may be stored.

[0089] In various example embodiment of the present invention the scan lines in at least one layer of at least a first three-dimensional article are fused with a first energy beam from a first energy beam source and at least one layer of at least a second three-dimensional article is fused with a second energy beam from a second energy beam source. More than one energy beam source may be used for fusing the scan lines. A first energy beam may emanate from an electron beam source and the second energy beam from a laser source. The first and second energy beam sources may be of the same type, i.e., a first and second electron beam source or a first and second laser beam source. The first and second energy beam sources may be used in sequence or simultaneously.

[0090] By using more than one energy beam source the build temperature of the three-dimensional build may more easily be maintained compared to if just one beam source is used. The reason for this is that two beam may be at more locations simultaneously than just one beam. Increasing the number of beam sources will further ease the control of the build temperature. By using a plurality of energy beam sources a first energy beam source may be used for melting the powder material and a second energy beam source may be used for heating the powder material in order to keep the build temperature within a predetermined temperature range.

[0091] In a fourth step 840 a first portion of the powder layer is provided simultaneous as fusing a second portion of the powder layer, wherein the second portion of the powder layer is fused along a line perpendicular to a rotational axis of the support structure. According to the invention the powder application and fusion takes place simultaneously. The powder is applied at a first portion of the work table 5 while the fusion is taken place on a second portion of the work table 5. The fusion may in various example embodiments take place along a line perpendicular to the rotational axis of the work plate 5. One example embodiment of a three dimensional article which is manufactured according to this invention where the fusion take place along a line perpendicular to the rotational axis is illustrated in Figure 6. In Figure 6 the rotational axis is along the z-axis. The three dimensional part 600 which is to be manufactured is centered around the Z-axis. A work plate is in Figure 6 rotating around the z-axis and simultaneously performing a downward movement depicted by arrow 610. Fusion may take place in an area denoted by 620. According to the invention a continuous slicing along Z is performed which may be described in a 2-dimensional angular coordinate system depicted at the bottom of Figure 6. The three-dimensional article is sliced continuously according to both a rotation and a translation along the z-axis at the same time. Continuous representation for a slicing thickness, or work plate drop, of Zmax/4 per turn is used in this example embodiment. Obviously any slicing thickness may be used other than this exemplified Zmax/4.

[0092] In Figure 7 a continuous slicing along the radius of the three-dimensional article is performed instead of as in Figure 6 along the z-axis. The three dimensional article 600 is identical in Figures 6 and 7. The three dimensional article is sliced in Figure 7 continuously according to a rotation along the X-axis. A beam scan line 601 moves progressively from the inner to the outer radius. Contentious representation for a slicing thickness, or radial distance move, of Rmax/4 per turn. According to the invention a continuous slicing along the radius of the three-dimensional article is performed which may be described in a 2-dimensional angular coordinate system depicted at the bottom of Figure 6. As can be seen, although the slicing mechanism is totally different in Figure 6 and 7 for the same three-dimensional object, the description in the relevant 2-dimensional angular coordinate system will be identical.

[0093] In another aspect of the invention it is provided a program element configured and arranged when executed on a computer to implement a method for forming at least one three-dimensional article through successive fusion of parts of a powder bed, which parts correspond to successive portions of the three-dimensional article. The program element may be installed in a computer readable storage medium. The computer readable storage medium may be the control unit 10 or another distinct and separate control unit, as may be desirable. The computer readable storage medium and the program element, which may comprise computer-readable program code portions embodied therein, may further be contained within a non-transitory computer program product. Further details regarding these features and configurations are provided, in turn, below.

[0094] As mentioned, various embodiments of the present invention may be implemented in various ways, including as non-transitory computer program products. A computer program product may include a non-transitory computer-readable storage medium storing applications, programs, program modules, scripts, source code, program code, object code, byte code, compiled code, interpreted code, machine code, executable instructions, and/or the like (also referred to herein as executable instructions, instructions for execution, program code, and/or similar terms used herein interchangeably). Such non-transitory computer-readable storage media include all computer-readable media (including volatile and non-volatile media).

[0095] In one embodiment, a non-volatile computer-readable storage medium may include a floppy disk, flexible disk, hard disk, solid-state storage (SSS) (e.g., a solid state drive (SSD), solid state card (SSC), solid state module (SSM)), enterprise flash drive, magnetic tape, or any other non-transitory magnetic medium, and/or the like. A non-volatile computer-readable storage medium may also include a punch card, paper tape, optical mark sheet (or any other physical medium with patterns of holes or other optically recognizable indicia), compact disc read only memory (CD-ROM), compact disc compact disc-rewritable (CD-RW), digital versatile disc (DVD), Blu-ray disc (BD), any other non-transitory optical medium, and/or the like. Such a non-volatile computer-readable storage medium may also include read-only memory (ROM), programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), flash memory (e.g., Serial, NAND, NOR, and/or the like), multimedia memory cards (MMC), secure digital (SD) memory cards, SmartMedia cards, CompactFlash (CF) cards, Memory Sticks, and/or the like. Further, a non-volatile computer-readable storage medium may also include conductivebridging random access memory (CBRAM), phase-change random access memory (PRAM), ferroelectric random-access memory (FeRAM), non-volatile random-access memory (NVRAM), magnetoresistive random-access memory (MRAM), resistive random-access memory (RRAM), Silicon-Oxide-Nitride-Oxide-Silicon memory (SONOS), floating junction gate random access memory (FJG RAM), Millipede memory, racetrack memory, and/or the like.

[0096] In one embodiment, a volatile computer-readable storage medium may include random access memory (RAM), dynamic random access memory (DRAM), static random access memory (SRAM), fast page mode dynamic random access memory (FPM DRAM), extended data-out dynamic random access memory (EDO DRAM), synchronous dynamic random access memory (SDRAM), double data rate synchronous dynamic random access memory (DDR SDRAM), double data rate type two synchronous dynamic random access memory (DDR2 SDRAM), double data rate type three synchronous dynamic random access memory (DDR3 SDRAM), Rambus dynamic random access memory (RDRAM), Twin Transistor RAM (TTRAM), Thyristor RAM (T-RAM), Zero-capacitor (Z-RAM), Rambus in-line memory module (RIMM), dual in-line memory module (DIMM), single in-line memory module (SIMM), video random access memory VRAM, cache memory (including various levels), flash memory, register memory, and/or the like. It will be appreciated that where embodiments are described to use a computer-readable storage medium, other types of computer-readable storage media may be substituted for or used in addition to the computer-readable storage media described above.

[0097] As should be appreciated, various embodiments of the present invention may also be implemented as methods, apparatus, systems, computing devices, computing entities, and/or the like, as have been described elsewhere herein. As such, embodiments of the present invention may take the form of an apparatus, system, computing device, computing entity, and/or the like executing instructions stored on a computer-readable storage medium to perform certain steps or operations. However, embodiments of the present invention may also take the form of an entirely hardware embodiment performing certain steps or operations.

[0098] Various embodiments are described below with reference to block diagrams and flowchart illustrations of apparatuses, methods, systems, and computer program products. It should be understood that each block of any of the block diagrams and flowchart illustrations, respectively, may be implemented in part by computer program instructions, e.g., as logical steps or operations executing on a processor in a computing system. These computer program instructions may be loaded onto a computer, such as a special purpose computer or other programmable data processing apparatus to produce a specifically-configured machine, such that the instructions which execute on the computer or other programmable data processing apparatus implement the functions specified in the flowchart block or blocks.

[0099] These computer program instructions may also be stored in a computer-readable memory that can direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory produce an article of manufacture including computer-readable instructions for implementing the functionality specified in the flowchart block or blocks. The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational steps to be performed on the computer or other programmable apparatus to produce a computer-implemented process such that the instructions that execute on the computer or other programmable apparatus provide operations for implementing the functions specified in the flowchart block or blocks.

[00100] Accordingly, blocks of the block diagrams and flowchart illustrations support various combinations for performing the specified functions, combinations of operations for performing the specified functions and program instructions for performing the specified functions. It should also be understood that each block of the block diagrams and flowchart illustrations, and combinations of blocks in the block diagrams and flowchart illustrations, could be implemented by special purpose hardware-based computer systems that perform the specified functions or operations, or combinations of special purpose hardware and computer instructions.

[00101] Figure 9 is a block diagram of an exemplary system **1020** that can be used in conjunction with various embodiments of the present invention. In at least the illustrated embodiment, the system **1020** may include one or more central computing devices **1110**, one or more distributed computing devices **1120**, and one or more distributed handheld or mobile devices **1300**, all configured in communication with a central server **1200** (or control unit) via one or more networks **1130**. While Figure 9 illustrates the various system entities as separate, standalone entities, the various embodiments are not limited to this particular architecture.

[00102] According to various embodiments of the present invention, the one or more networks **1130** may be capable of supporting communication in accordance with any one or more of a number of second-generation (2G), 2.5G, third-generation (3G), and/or fourthgeneration (4G) mobile communication protocols, or the like. More particularly, the one or more networks **1130** may be capable of supporting communication in accordance with 2G wireless communication protocols IS-136 (TDMA), GSM, and IS-95 (CDMA). Also, for example, the one or more networks **1130** may be capable of supporting communication in accordance with 2.5G wireless communication protocols GPRS, Enhanced Data GSM Environment (EDGE), or the like. In addition, for example, the one or more networks **1130** may be capable of supporting communication in accordance with 3G wireless communication protocols such as Universal Mobile Telephone System (UMTS) network employing Wideband Code Division Multiple Access (WCDMA) radio access technology. Some narrow-band AMPS (NAMPS), as well as TACS, network(s) may also benefit from embodiments of the present invention, as should dual or higher mode mobile stations (e.g., digital/analog or TDMA/CDMA/analog phones). As yet another example, each of the components of the system **1020** may be configured to communicate with one another in accordance with techniques such as, for example, radio frequency (RF), Bluetooth™, infrared (IrDA), or any of a number of different wired or wireless networking techniques, including a wired or wireless Personal Area Network ("PAN"), Local Area Network ("LAN"), Metropolitan Area Network ("MAN"), Wide Area Network ("WAN"), or the like.

[00103] Although the device(s) **1110-1300** are illustrated in Figure 9 as communicating with one another over the same network **1130**, these devices may likewise communicate over multiple, separate networks.

[00104] According to one embodiment, in addition to receiving data from the server **1200**, the distributed devices **1110**, **1120**, and/or **1300** may be further configured to collect and transmit data on their own. In various embodiments, the devices **1110**, **1120**, and/or **1300** may be capable of receiving data via one or more input units or devices, such as a keypad, touchpad, barcode scanner, radio frequency identification (RFID) reader, interface card (e.g., modem, etc.) or receiver. The devices **1110**, **1120**, and/or **1300** may further be capable of storing data to one or more volatile or non-volatile memory modules, and outputting the data via one or more output units or devices, for example, by displaying data to the user operating the device, or by transmitting data, for example over the one or more networks **1130**.

[00105] In various embodiments, the server **1200** includes various systems for performing one or more functions in accordance with various embodiments of the present invention, including those more particularly shown and described herein. It should be understood, however, that the server **1200** might include a variety of alternative devices for performing one or more like functions, without departing from the spirit and scope of the present invention. For example, at least a portion of the server **1200**, in certain embodiments, may be located on the distributed device(s) **1110**, **1120**, and/or the handheld or mobile device(s) **1300**, as may be desirable for particular applications. As will be described in further detail below, in at least one embodiment, the handheld or mobile device(s) **1300** may contain one or more mobile applications **1330** which may be configured so as to provide a user interface for communication with the server **1200**, all as will be likewise described in further detail below.

[00106] Figure 10A is a schematic diagram of the server **1200** according to various embodiments. The server **1200** includes a processor **1230** that communicates with other elements within the server via a system interface or bus **1235**. Also included in the server **1200** is a display/input device **1250** for receiving and displaying data. This display/input device **1250** may be, for example, a keyboard or pointing device that is used in combination with a monitor. The server **1200** further includes memory **1220**, which typically includes both read only memory (ROM) **1226** and random access memory (RAM) **1222**. The server's ROM **1226** is used to store a basic input/output system **1224** (BIOS), containing the basic routines that help to transfer information between elements within the server **1200**. Various ROM and RAM configurations have been previously described herein.

[00107] In addition, the server **1200** includes at least one storage device or program storage **210**, such as a hard disk drive, a floppy disk drive, a CD Rom drive, or optical disk drive, for storing information on various computer-readable media, such as a hard disk, a removable magnetic disk, or a CD-ROM disk. As will be appreciated by one of ordinary skill in the art, each of these storage devices **1210** are connected to the system bus **1235** by an appropriate interface. The storage devices **1210** and their associated computer-readable media provide nonvolatile storage for a personal computer. As will be appreciated by one of ordinary skill in the art, the computer-readable media described above could be replaced by any other type of computer-readable media known in the art. Such media include, for example, magnetic cassettes, flash memory cards, digital video disks, and Bernoulli cartridges.

[00108] Although not shown, according to an embodiment, the storage device **1210** and/or memory of the server **1200** may further provide the functions of a data storage device, which may store historical and/or current delivery data and delivery conditions that may be accessed by the server **1200**. In this regard, the storage device **1210** may comprise one or more databases. The term “database” refers to a structured collection of records or data that is stored in a computer system, such as via a relational database, hierarchical database, or network database and as such, should not be construed in a limiting fashion.

[00109] A number of program modules (e.g., exemplary modules **1400-1700**) comprising, for example, one or more computer-readable program code portions executable by the processor **1230**, may be stored by the various storage devices **1210** and within RAM **1222**. Such program modules may also include an operating system **1280**. In these and other embodiments, the various modules **1400**, **1500**, **1600**, **1700** control certain aspects of the operation of the server **1200** with the assistance of the processor **1230** and operating system **1280**. In still other embodiments, it should be understood that one or more additional and/or alternative modules may also be provided, without departing from the scope and nature of the present invention.

[00110] In various embodiments, the program modules **1400**, **1500**, **1600**, **1700** are executed by the server **1200** and are configured to generate one or more graphical user interfaces, reports, instructions, and/or notifications/alerts, all accessible and/or transmittable to various users of the system **1020**. In certain embodiments, the user interfaces, reports, instructions, and/or notifications/alerts may be accessible via one or more networks **1130**, which may include the Internet or other feasible communications network, as previously discussed.

[00111] In various embodiments, it should also be understood that one or more of the modules **1400**, **1500**, **1600**, **1700** may be alternatively and/or additionally (e.g., in duplicate) stored locally on one or more of the devices **1110**, **1120**, and/or **1300** and may be executed by one or more processors of the same. According to various embodiments, the modules **1400**, **1500**, **1600**, **1700** may send data to, receive data from, and utilize data contained in one or more databases, which may be comprised of one or more separate, linked and/or networked databases.

[00112] Also located within the server **1200** is a network interface **1260** for interfacing and communicating with other elements of the one or more networks **1130**. It will be appreciated by one of ordinary skill in the art that one or more of the server **1200** components may be located geographically remotely from other server components. Furthermore, one or more of the server **1200** components may be combined, and/or additional components performing functions described herein may also be included in the server.

[00113] While the foregoing describes a single processor **1230**, as one of ordinary skill in the art will recognize, the server **1200** may comprise multiple processors operating in conjunction with one another to perform the functionality described herein. In addition to the memory **1220**, the processor **1230** can also be connected to at least one interface or other means for displaying, transmitting and/or receiving data, content or the like. In this regard, the interface(s) can include at least one communication interface or other means for transmitting and/or receiving data, content or the like, as well as at least one user interface that can include a display and/or a user input interface,, as will be described in further detail below. The user input interface, in turn, can comprise any of a number of devices allowing the entity to receive data from a user, such as a keypad, a touch display, a joystick or other input device.

[00114] Still further, while reference is made to the "server" **1200**, as one of ordinary skill in the art will recognize, embodiments of the present invention are not limited to traditionally defined server architectures. Still further, the system of embodiments of the present invention is not limited to a single server, or similar network entity or mainframe computer system. Other similar architectures including one or more network entities operating in conjunction with one another to provide the functionality described herein may likewise be used without departing from the spirit and scope of embodiments of the present invention. For example, a mesh network of two or more personal computers (PCs), similar electronic devices, or handheld portable devices, collaborating with one another to provide the functionality described herein in association with the server **1200** may likewise be used without departing from the spirit and scope of embodiments of the present invention.

[00115] According to various embodiments, many individual steps of a process may or may not be carried out utilizing the computer systems and/or servers described herein, and the degree of computer implementation may vary, as may be desirable and/or beneficial for one or more particular applications.

[00116] Figure 10B provides an illustrative schematic representative of a mobile device **1300** that can be used in conjunction with various embodiments of the present invention. Mobile devices **1300** can be operated by various parties. As shown in Figure 10B, a mobile device **1300** may include an antenna **1312**, a transmitter **1304** (e.g., radio), a receiver **1306** (e.g., radio), and a processing element **1308** that provides signals to and receives signals from the transmitter **1304** and receiver **1306**, respectively.

[00117] The signals provided to and received from the transmitter **1304** and the receiver **1306**, respectively, may include signaling data in accordance with an air interface standard of applicable wireless systems to communicate with various entities, such as the server **1200**, the distributed devices **1110**, **1120**, and/or the like. In this regard, the mobile device **1300** may be capable of operating with one or more air interface standards, communication protocols, modulation types, and access types. More particularly, the mobile device **1300** may operate in accordance with any of a number of wireless communication standards and protocols. In a particular embodiment, the mobile device **1300** may operate in accordance with multiple wireless communication standards and protocols, such as GPRS, UMTS, CDMA2000, 1xRTT, WCDMA, TD-SCDMA, LTE, E-UTRAN, EVDO, HSPA, HSDPA, Wi-Fi, WiMAX, UWB, IR protocols, Bluetooth protocols, USB protocols, and/or any other wireless protocol.

[00118] Via these communication standards and protocols, the mobile device **1300** may according to various embodiments communicate with various other entities using concepts such as Unstructured Supplementary Service data (USSD), Short Message Service (SMS), Multimedia Messaging Service (MMS), Dual-Tone Multi-Frequency Signaling (DTMF), and/or *Subscriber Identity Module* Dialer (SIM dialer). The mobile device **1300** can also download changes, add-ons, and updates, for instance, to its firmware, software (e.g., including executable instructions, applications, program modules), and operating system.

[00119] According to one embodiment, the mobile device **1300** may include a location determining device and/or functionality. For example, the mobile device **1300** may include a GPS module adapted to acquire, for example, latitude, longitude, altitude, geocode, course, and/or speed data. In one embodiment, the GPS module acquires data, sometimes known as ephemeris data, by identifying the number of satellites in view and the relative positions of those satellites.

[00120] The mobile device **1300** may also comprise a user interface (that can include a display **1316** coupled to a processing element **1308**) and/or a user input interface (coupled to a processing element **308**). The user input interface can comprise any of a number of devices allowing the mobile device **1300** to receive data, such as a keypad **1318** (hard or soft), a touch display, voice or motion interfaces, or other input device. In embodiments including a keypad **1318**, the keypad can include (or cause display of) the conventional numeric (0-9) and related keys (#, *), and other keys used for operating the mobile device **1300** and may include a full set of alphabetic keys or set of keys that may be activated to provide a full set of alphanumeric keys. In addition to providing input, the user input interface can be used, for example, to activate or deactivate certain functions, such as screen savers and/or sleep modes.

[00121] The mobile device **1300** can also include volatile storage or memory **1322** and/or non-volatile storage or memory **1324**, which can be embedded and/or may be removable. For example, the non-volatile memory may be ROM, PROM, EPROM, EEPROM, flash memory, MMCs, SD memory cards, Memory Sticks, CBRAM, PRAM, FeRAM, RRAM, SONOS, racetrack memory, and/or the like. The volatile memory may be RAM, DRAM, SRAM, FPM DRAM, EDO DRAM, SDRAM, DDR SDRAM, DDR2 SDRAM, DDR3 SDRAM, RDRAM, RIMM, DIMM, SIMM, VRAM, cache memory, register memory, and/or the like. The volatile and non-volatile storage or memory can store databases, database instances, database mapping systems, data, applications, programs, program modules, scripts, source code, object code, byte code, compiled code, interpreted code, machine code, executable instructions, and/or the like to implement the functions of the mobile device **1300**.

[00122] The mobile device **1300** may also include one or more of a camera **1326** and a mobile application **1330**. The camera **1326** may be configured according to various embodiments as an additional and/or alternative data collection feature, whereby one or more items may be read, stored, and/or transmitted by the mobile device **1300** via the camera. The mobile application **1330** may further provide a feature via which various tasks may be performed with the mobile device **1300**. Various configurations may be provided, as may be desirable for one or more users of the mobile device **1300** and the system **1020** as a whole.

[00123] It will be appreciated that many variations of the above systems and methods are possible, and that deviation from the above embodiments are possible, but yet within the scope of the claims. Many modifications and other embodiments of the invention set forth herein will come to mind to one skilled in the art to which these inventions pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Such modifications may, for example, involve using a different source of ray gun than the exemplified electron beam such as laser beam. Other materials than metallic powder may be used such as powders of polymers and powder of ceramics. Therefore, it is to be understood that the inventions are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims.

Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

CLAIMS

1. A method for forming at least one three-dimensional article through successive fusion of parts of a powder bed, which parts correspond to successive portions of the three-dimensional article, said method comprising the steps of:

   providing at least one model of said three-dimensional article, wherein said model of said three-dimensional article is described in a two-dimensional angular coordinate system;

   applying a powder layer on a support structure;

   directing at least one energy beam from at least one energy beam source, said energy beam source being at least one of an electromagnetic energy beam source or a charged particle beam source, over said powder layer causing said powder layer to fuse in first selected locations according to said model to form a first portion of said three-dimensional article; and

   providing a first portion of said powder layer simultaneous as fusing a second portion of said powder layer, wherein said second portion of the powder layer is fused along a line perpendicular to a rotational axis of said support structure.

2. The method according to claim 1, wherein a single beam is scanning along said line perpendicular to the rotational axis.

3. The method according to claim 1, wherein a plurality of beams are configured for melting along said line perpendicular to the rotational axis simultaneously.

4. The method according to claim 1, wherein said rotational axis is along the Z-axis and said at least one beam is fusing in an x-y plane.

5. The method according to claim 1, further comprising the step of moving said support structure in z-direction at a predetermined speed while rotating said support structure at a predetermined speed.

6. The method according to claim 1, wherein said support structure is a horizontal plate.

7. The method according to claim 6, wherein said energy beam is provided off axis with respect to said rotational axis of said support structure.

8. The method according to claim 1, wherein said support structure is continuously moving in said z-direction at a predetermined speed.

9. The method according to claim 1, wherein said rotational axis of said support structure is essentially horizontal and wherein said second portion of the powder layer is fused along a line in parallel to a rotational axis of said support structure instead of perpendicular to said rotational axis.

10. The method according to claim 9, wherein a single beam is scanning along said line parallel to the rotational axis of the support structure.

11. The method according to claim 9, wherein a plurality of beams is configured for melting said line parallel to the rotational axis of the support structure simultaneously.

12. The method according to claim 11, wherein said line perpendicular to said rotational axis is at least one of a straight line or a meandering line.

13. The method according to claim 8, wherein said support structure is a cylinder with a radius, which radius is increasing from a first to a second layer proportional to an applied powder layer thickness.

14. The method according to claim 1, wherein a rotational axis of the model is coincidental with the rotational axis of the three-dimensional article built on said support structure.

15. The method according to claim 1, wherein said powder layer is provided continuously on said support structure during the formation of said three-dimensional article.

16. The method according to claim 1, wherein said support structure is rotating at least one of clockwise or anticlockwise during the formation of the three-dimensional article.

17. The method according to claim 1, further comprising the step of preheating a third portion of said powder layer.

18. The method according to claim 17, wherein said preheating is performed by using at least one of the energy sources used for fusing said powder layer.

19. The method according to claim 17, wherein said preheating is performed by using an energy source not used for fusing said powder layer.

20. The method according to claim 1, wherein said step of directing said at least one energy beam from at least one energy beam source and over said powder layer causing said powder layer to fuse in first selected locations comprises deflecting said at least one energy beam via at least one mirror positioned in the pathway between said at least one energy beam source and said support structure.

21. The method according to Claim 20, wherein said at least one mirror is a movable mirror.

22. The method according to claim 1, wherein at least said steps of providing said first portion of said powder layer simultaneous as fusing said second portion of said powder layer occurs in a vacuum chamber.

23. The method according to Claim 5, wherein beam movement is coordinated with said rotational movement via an associated control unit.

24. A program element configured and arranged when executed on a computer to implement a method for forming at least one three-dimensional article through successive fusion of parts of a powder bed, which parts correspond to successive portions of the three-dimensional article, said method comprising the step of:

providing at least one model of said three-dimensional article, wherein said model of said three-dimensional article is described in a two-dimensional angular coordinate system;

applying a powder layer on a support structure;

directing at least one energy beam from at least one energy beam source, said energy beam source being at least one of an electromagnetic energy beam source or a charged particle beam source, over said powder layer causing said powder layer to fuse in first selected locations according to said model to form a first portion of said three-dimensional article; and

providing a first portion of said powder layer simultaneous as fusing a second portion of said powder layer, wherein said second portion of the powder layer is fused along a line perpendicular to a rotational axis of said support structure.

25. A non-transitory computer readable medium having stored thereon the program element according to claim 24.

26. A computer program product comprising at least one non-transitory computer-readable storage medium having computer-readable program code portions embodied therein, the computer-readable program code portions comprising:

an executable portion configured for, upon receipt of at least one model of said three-dimensional article, wherein said model of said three-dimensional article is described in a two-dimensional angular coordinate system, applying a powder layer on a support structure;

an executable portion configured for directing at least one energy beam from at least one energy beam source, said energy beam source being at least one of an electromagnetic energy beam source or a charged particle beam source, over said powder layer causing said powder layer to fuse in first selected locations according to said model to form a first portion of said three-dimensional article; and

an executable portion configured for providing a first portion of said powder layer simultaneous as fusing a second portion of said powder layer, wherein said second portion of the powder layer is fused along a line perpendicular to a rotational axis of said support structure.

27. An apparatus for forming a three-dimensional article through successive fusion of parts of a powder bed, which parts corresponds to successive cross sections of the three-dimensional article, said apparatus comprising:

a control unit having stored thereon a computer model of said three-dimensional article;

at least one energy beam from at least one energy beam source, said energy beam source being at least one of an electromagnetic energy beam source or a charged particle beam source, said at least one energy beam being configured to be directed, via said control unit, over said powder layer so as to cause said powder layer to fuse in first selected locations according to said model to form a first portion of said three-dimensional article; and

a rotational support structure, wherein said rotation of said rotational support structure occurs about a rotational axis of said support structure, such that a second portion of the powder layer is fused along a line perpendicular to said rotational axis simultaneous with said formation of said first portion.

28. The apparatus of Claim 27, further comprising at least one mirror positioned in a pathway between said at least one energy beam source and said support

structure, said at least one mirror being configured for, via said control unit, directing said at least one energy beam.

29. The apparatus of Claim 28, wherein said at least one mirror is a movable mirror.

30. The apparatus of Claim 27, wherein said at least one energy beam is oriented for scanning along a line parallel to and offset relative to said rotational axis of said support structure.

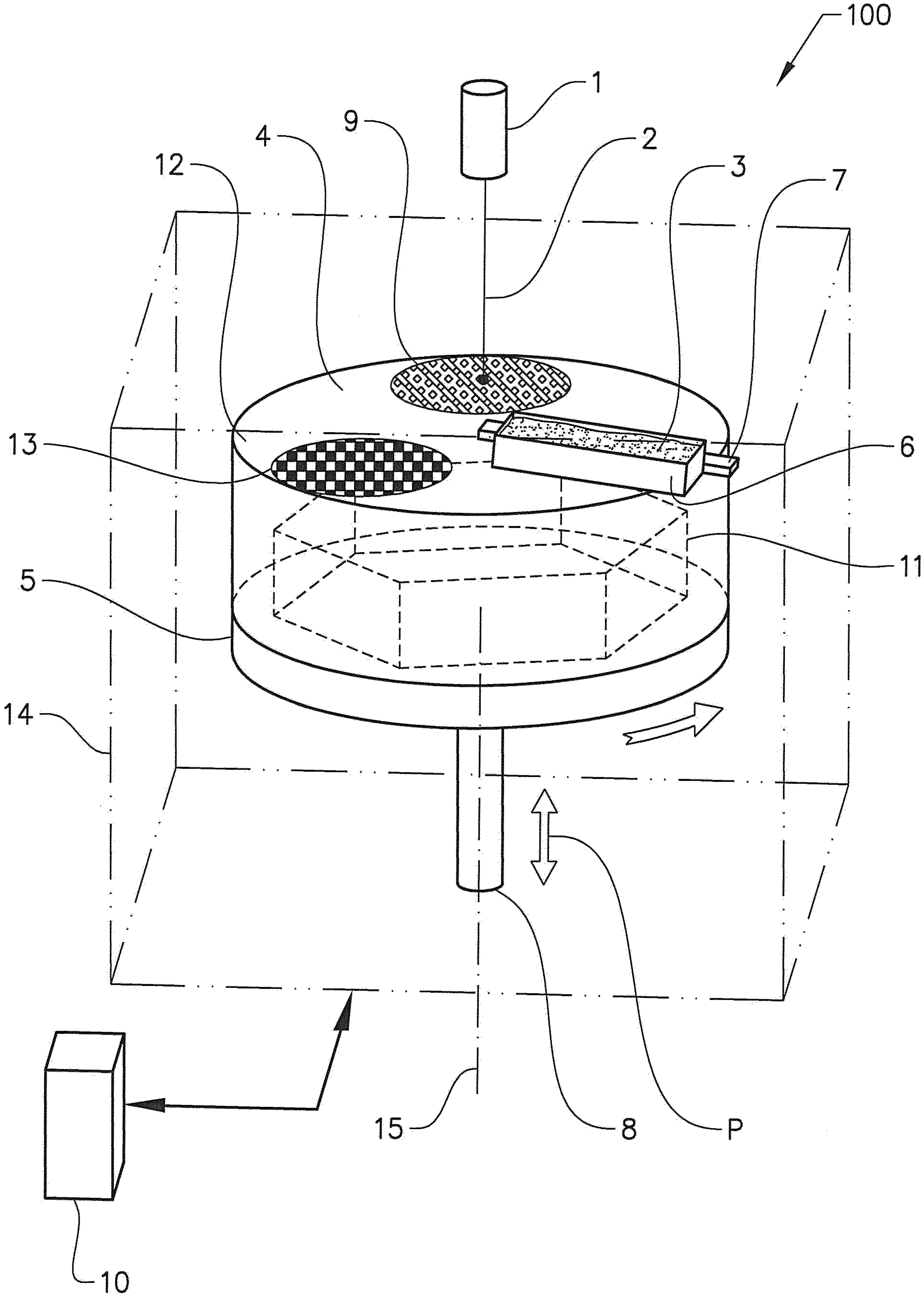


FIG. 1

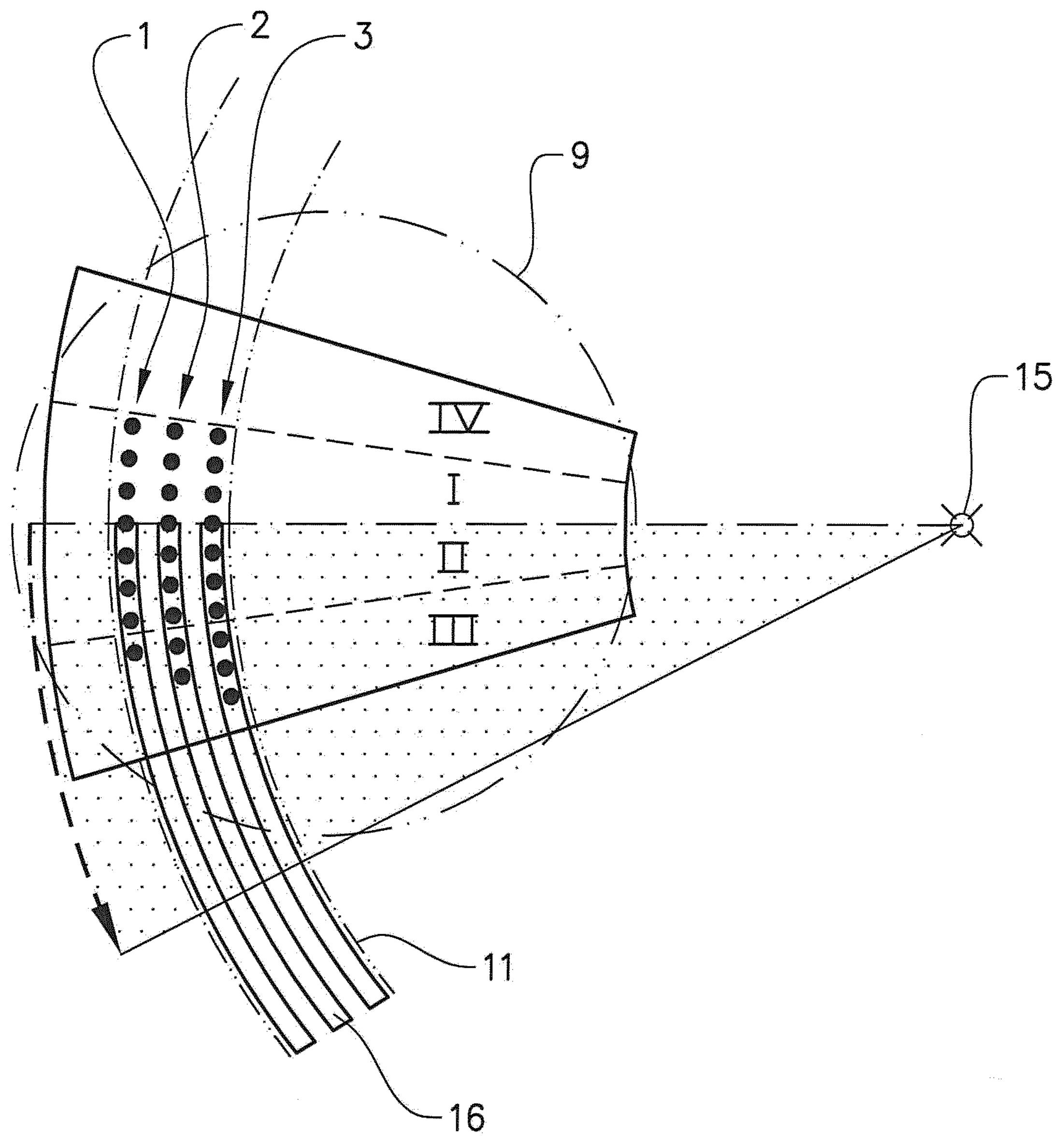


FIG. 2

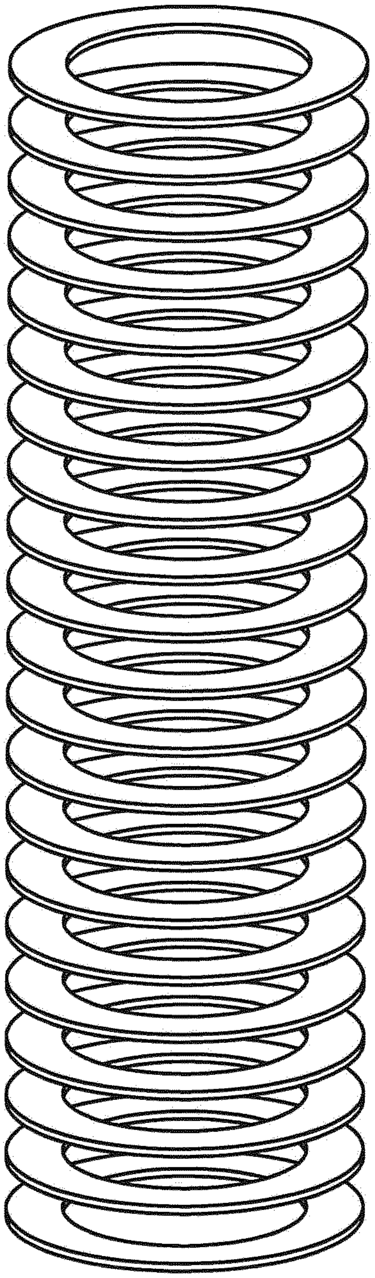


FIG. 3

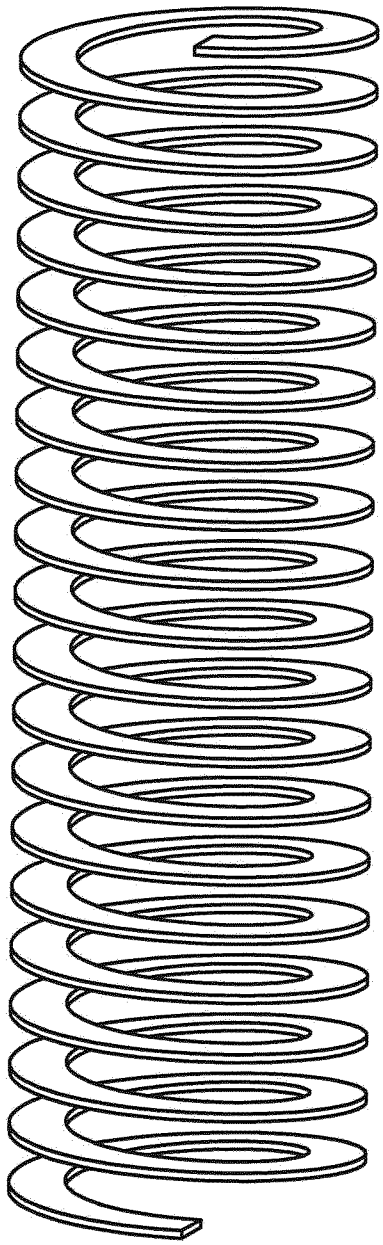


FIG. 4

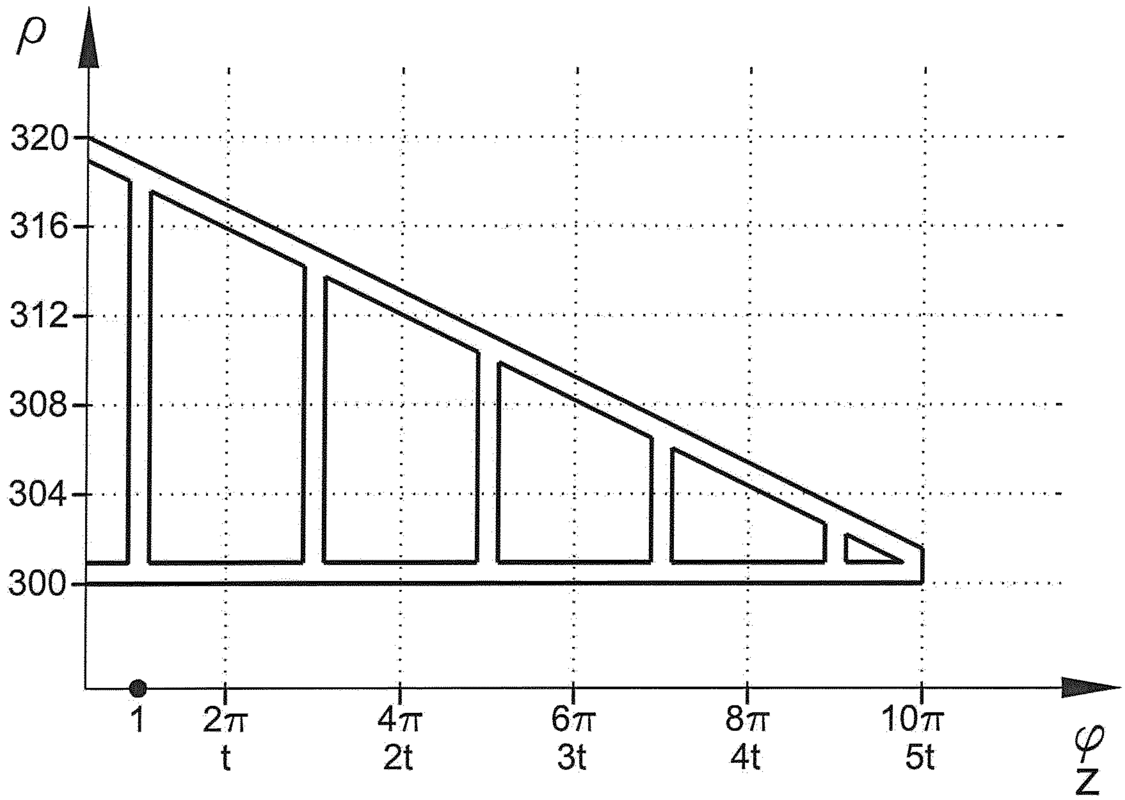

ρ
320
316
312
308
304
300
1
2π
t
4π
2t
6π
3t
8π
4t
10π
5t
φ
z

FIG. 5a

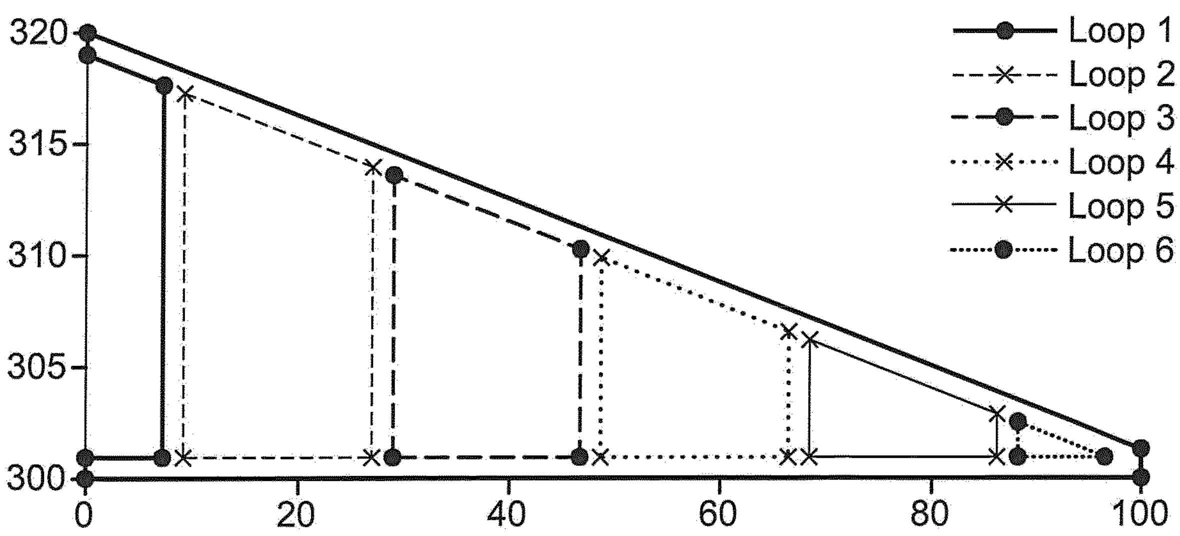

320
315
310
305
300
0
20
40
60
80
100
Loop 1
Loop 2
Loop 3
Loop 4
Loop 5
Loop 6

FIG. 5b

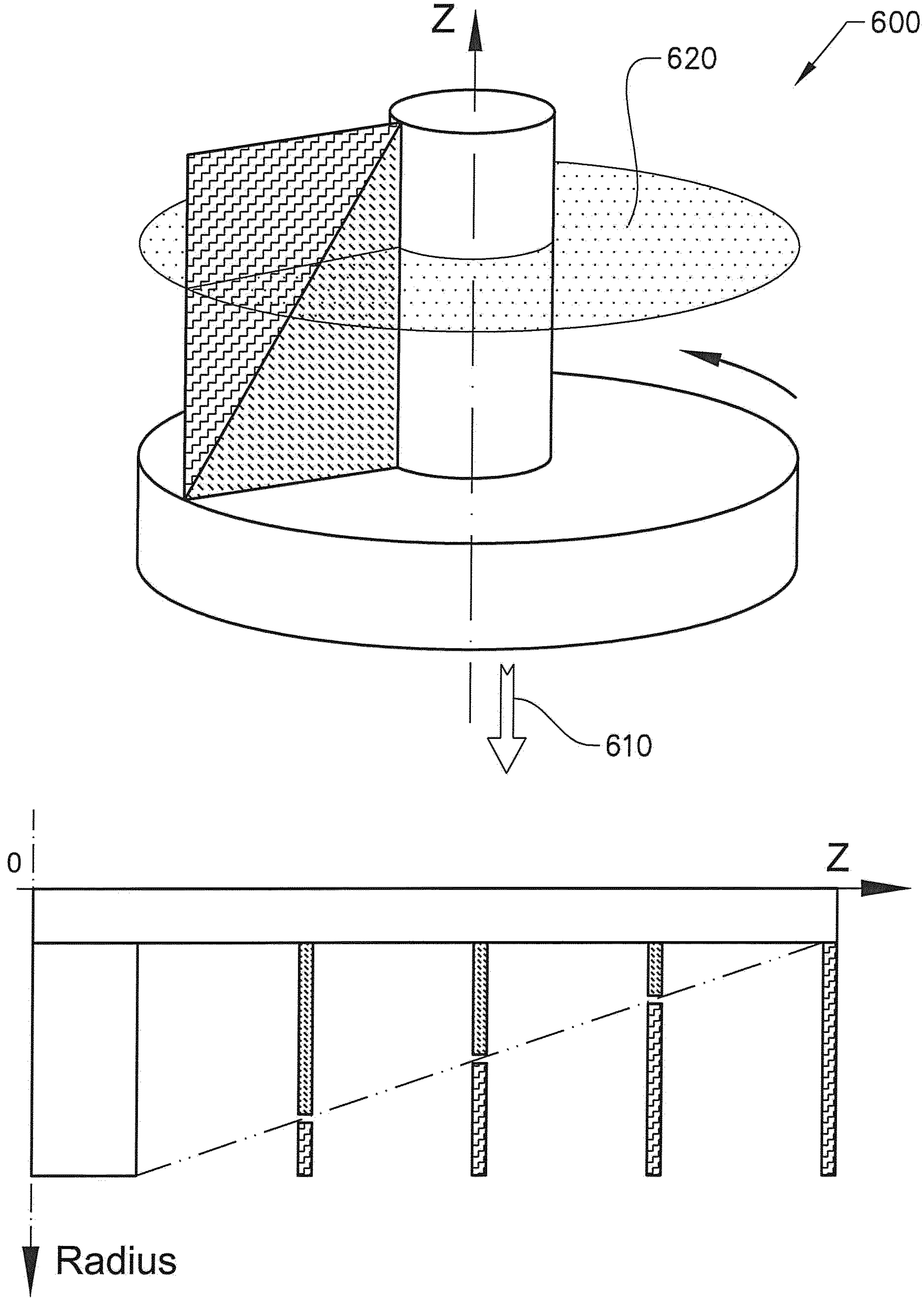


FIG. 6

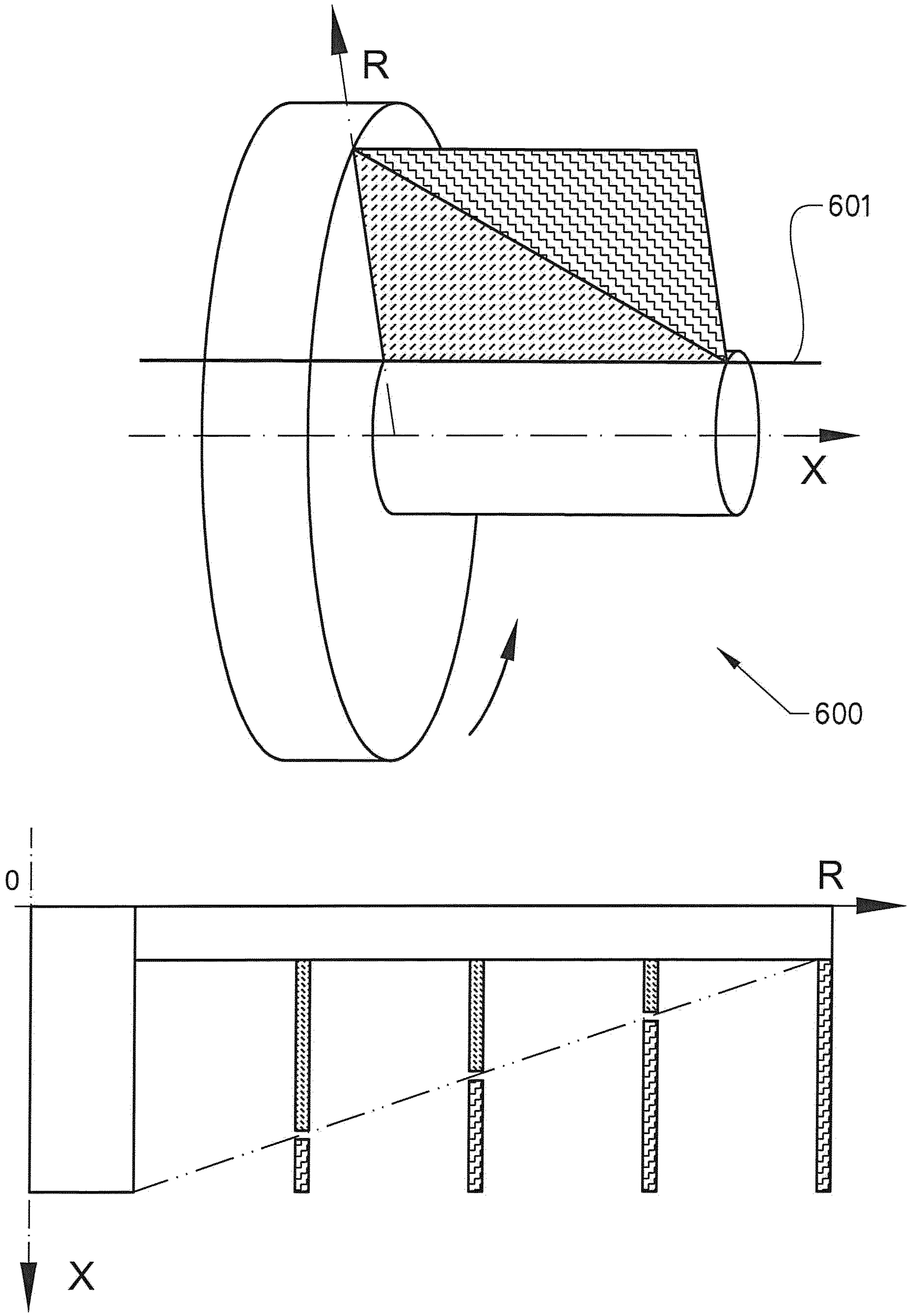


FIG. 7

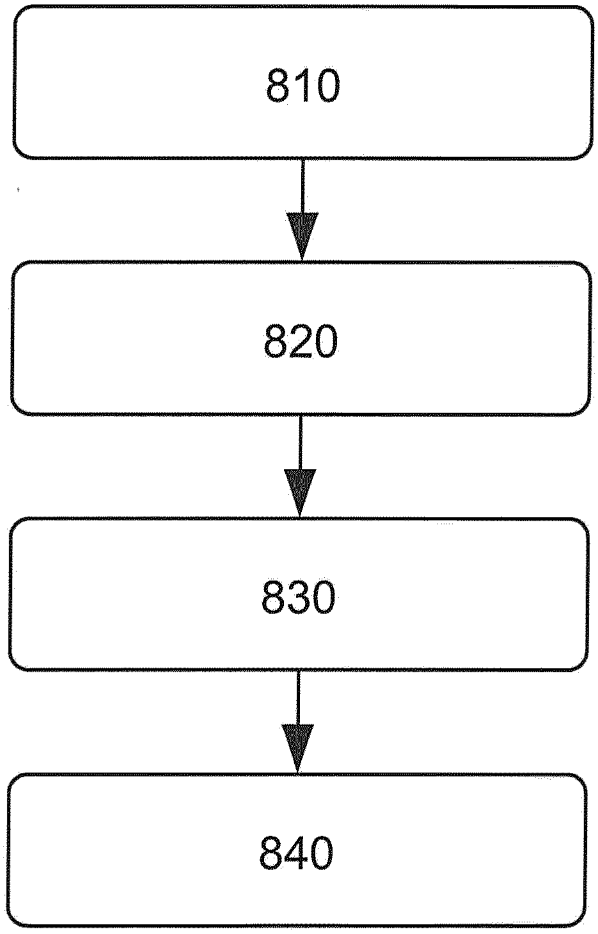


FIG. 8

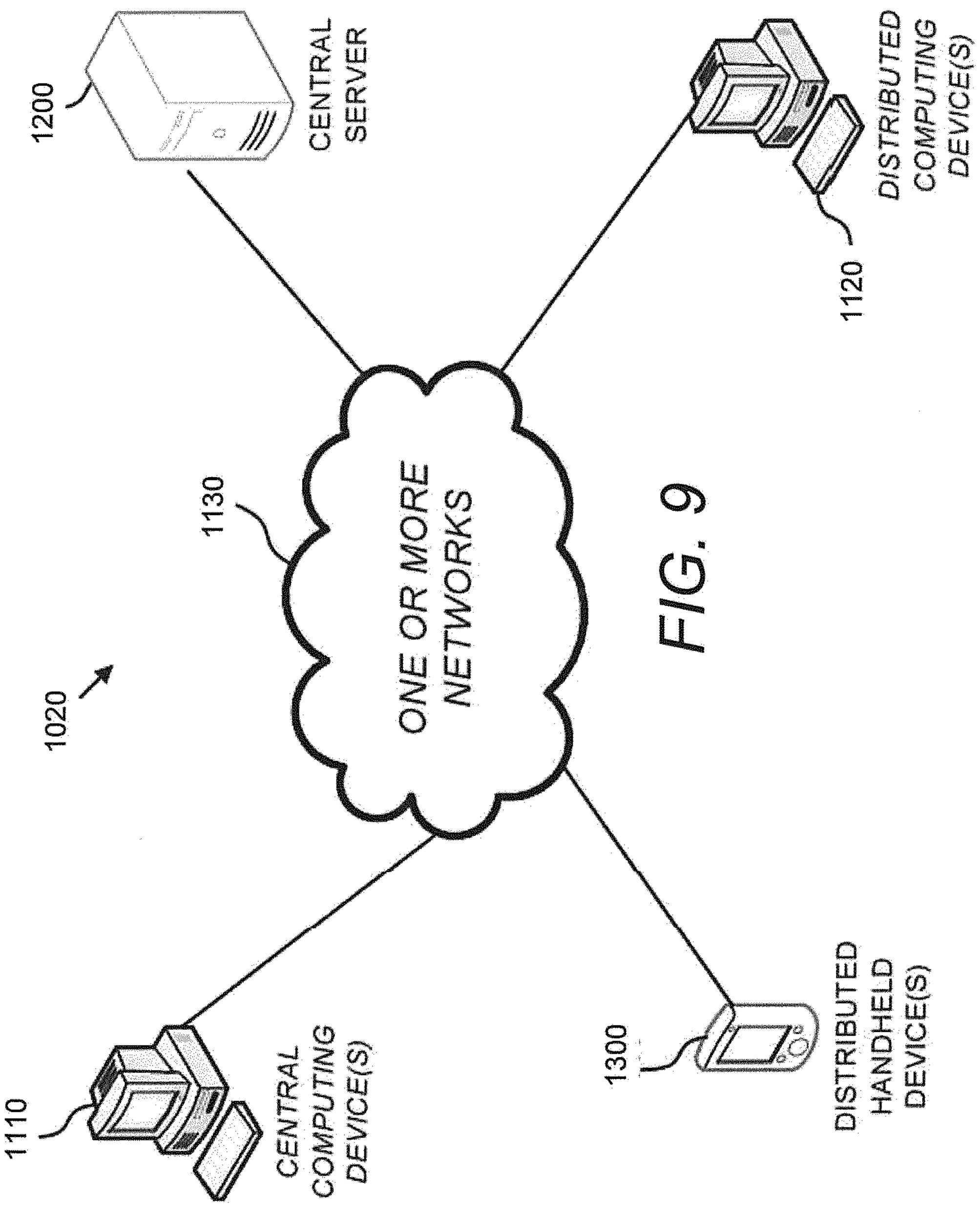
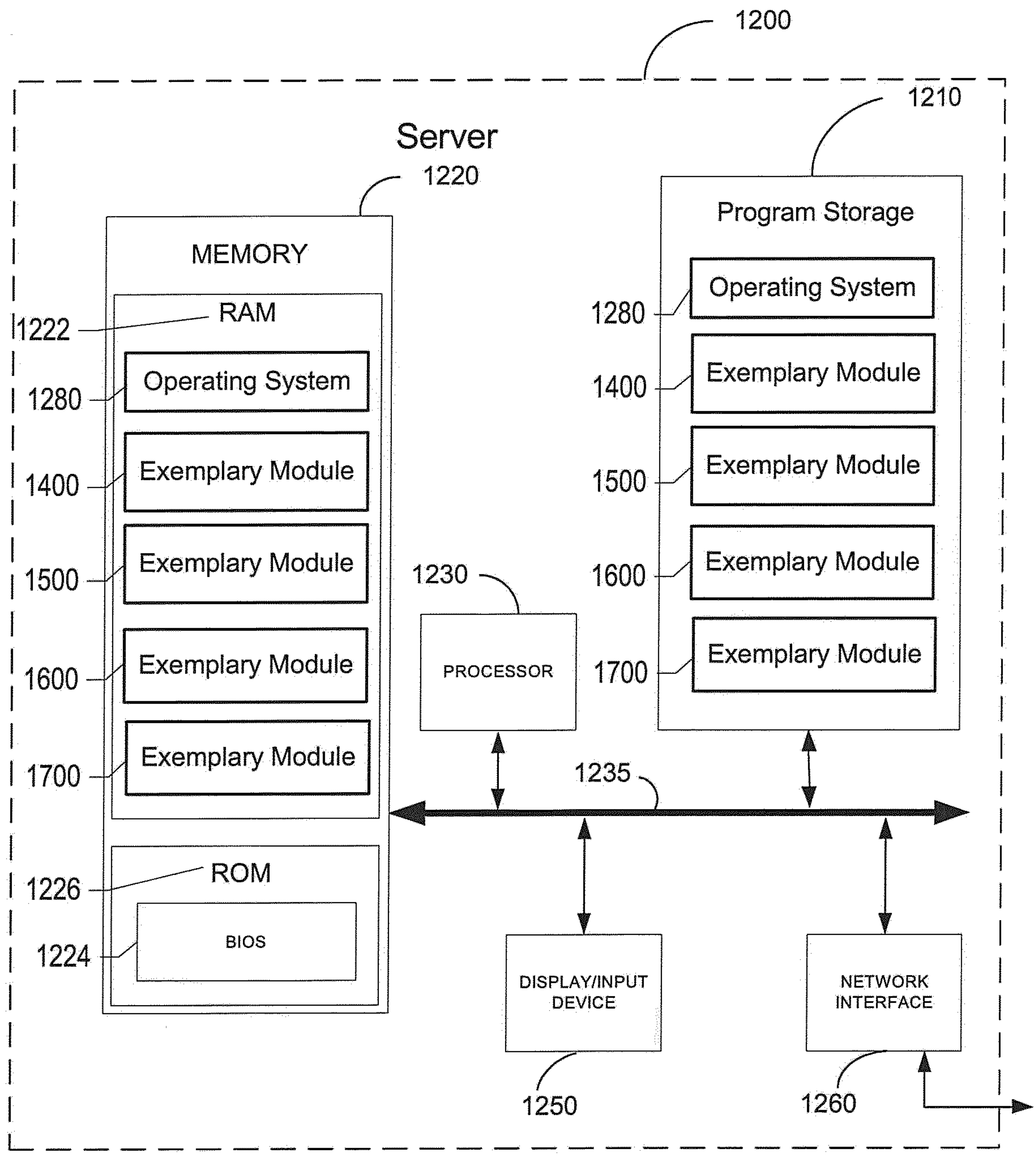

1020
1200
CENTRAL SERVER
1130
ONE OR MORE NETWORKS
1120
DISTRIBUTED COMPUTING DEVICE(S)
1110
CENTRAL COMPUTING DEVICE(S)
1300
DISTRIBUTED HANDHELD DEVICE(S)

FIG. 9


1200
1210
Server
1220
MEMORY
Program Storage
RAM
1222
Operating System
1280
Exemplary Module
1400
Exemplary Module
1500
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1600
Exemplary Module
1700
Operating System
1280
Exemplary Module
1400
Exemplary Module
1500
Exemplary Module
1600
Exemplary Module
1700
1230
PROCESSOR
1235
ROM
1226
BIOS
1224
DISPLAY/INPUT DEVICE
1250
NETWORK INTERFACE
1260

FIG. 10A

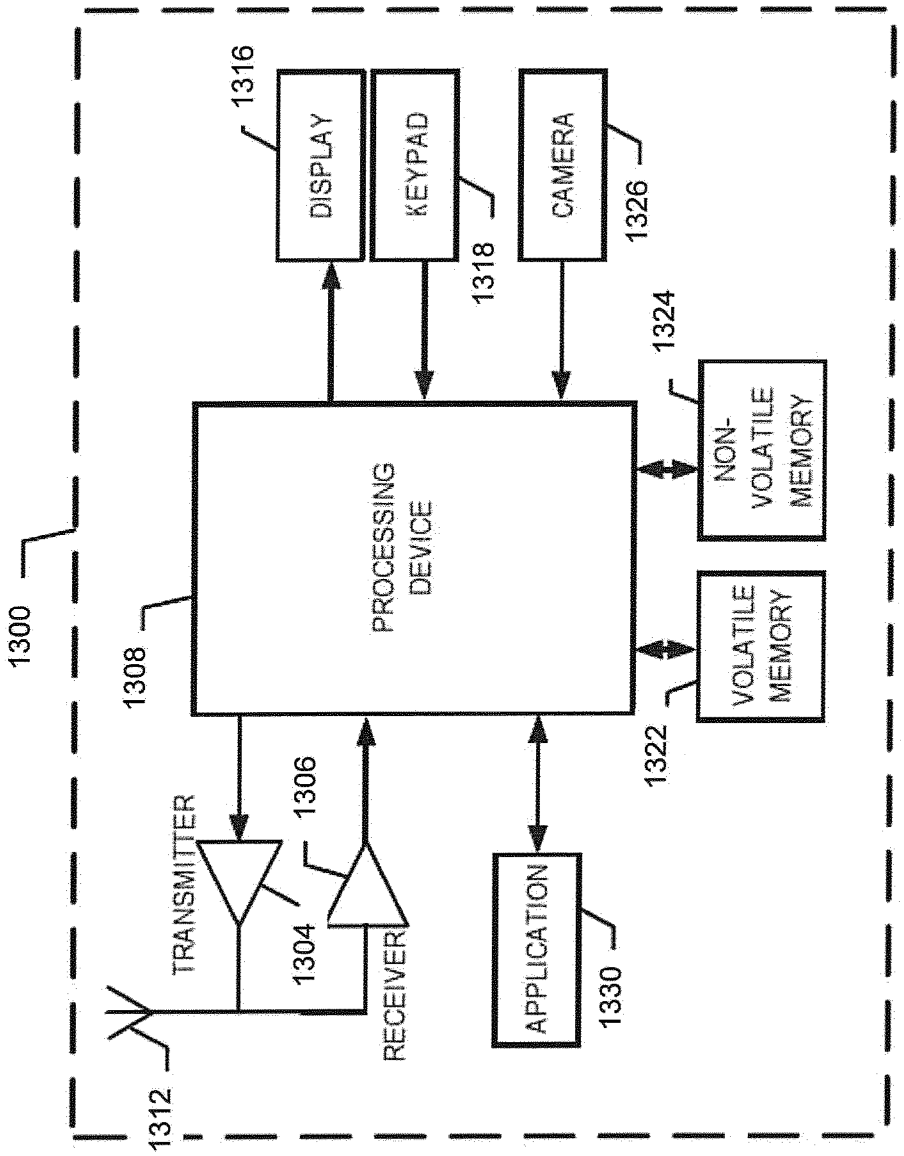
1300
1316
DISPLAY
KEYPAD
1318
CAMERA
1326
1324
PROCESSING DEVICE
1308
NON-VOLATILE MEMORY
VOLATILE MEMORY
1322
TRANSMITTER
1306
1304
RECEIVER
1312
APPLICATION
1330

FIG. 10B

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/078215

A. CLASSIFICATION OF SUBJECT MATTER
INV. B29C70/52 B29C67/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B29C

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 10 2013 210242 A1 (SIEMENS AG [DE]) 4 December 2014 (2014-12-04) paragraphs [0004], [0014], [0015]; claims; figures	1,2,4-8, 15-29
X	EP 1 358 994 A1 (BEGO MEDICAL AG [DE]) 5 November 2003 (2003-11-05) page 0006; claims	1,4-8, 15-19, 24-27
X	DE 102 35 434 A1 (EOS ELECTRO OPTICAL SYST [DE]) 12 February 2004 (2004-02-12) claim 20	1,2,4-8, 15, 17-19, 24-27

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 February 2016	22/02/2016

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Van Wallene, Allard

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/078215

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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X	WO 2004/108398 A1 (UNIV LIVERPOOL [GB]; SUTCLIFFE CHRISTOPHER [GB]) 16 December 2004 (2004-12-16) page 10, last paragraph - page 11, paragraph 1; claims 6,7,10 page 4, last paragraph - page 5, paragraph 3	1-8, 15-19, 23-27
X	WO 2011/011818 A1 (ZYDEX PTY LTD [AU]; ELSEY JUSTIN [AU]) 3 February 2011 (2011-02-03) figure 1	9-13,30

1

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Information on patent family members

International application No
PCT/EP2015/078215

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		US 2008109102 A1	08-05-2008
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		CN 102481729 A	30-05-2012
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		WO 2011011818 A1	03-02-2011