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(71) Applicant(s):
Stratasys Powder Production Ltd
Suite 1, 7th Floor 50 Broadway, London, SW1H 0BL,
United Kingdom

(72) Inventor(s):
Christopher Pleass

(74) Agent and/or Address for Service:
Stratasys Powder Production Ltd
Intellectual Property Team, Suite 1, 3rd Floor,
11-12 St. James's Square, London, SW1Y 4LB,
United Kingdom

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WO 2008/120183 A1 **CN 107803987 B**
US 20170095979 A1

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(54) Title of the Invention: **Method for generating slice data for the layerwise manufacture of 3D objects from particulate material**
Abstract Title: **METHOD FOR GENERATING SLICE DATA FOR THE LAYERWISE MANUFACTURE OF 3D OBJECTS FROM PARTICULATE MATERIAL**

(57) A method for generating slice data from a virtual build volume for the additive manufacture of one or more objects within an actual build volume, comprises the steps of: receiving one or more object models; (b) positioning the model(s) in the virtual build volume; (c) generating slice data by dividing the virtual build volume into groups of parallel planar slices stacked in the vertical direction, each slice corresponding to a layer within the actual build volume; wherein the slice thickness is progressively increased, preferably non-linearly, from one group to the next, such that the slice thickness of an upper group is greater than the slice thickness of a lower group with respect to the vertical direction. The slice thickness of upper layers may be more than the intended layer thickness in the actual build volume; the intended layer thickness is constant. The increase in slice thickness may be determined empirically or may be determined from a model based on one or more build parameters to determine a non-linear expansion function. The method allows for better compensation to dimensional inaccuracies caused by shrinkage and compression of lower layers.

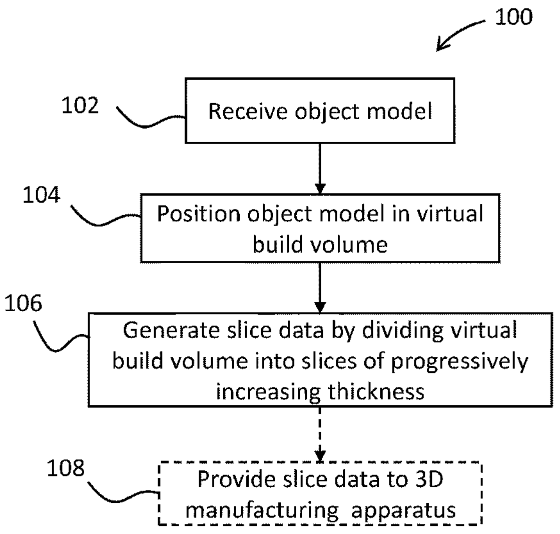


Fig. 1

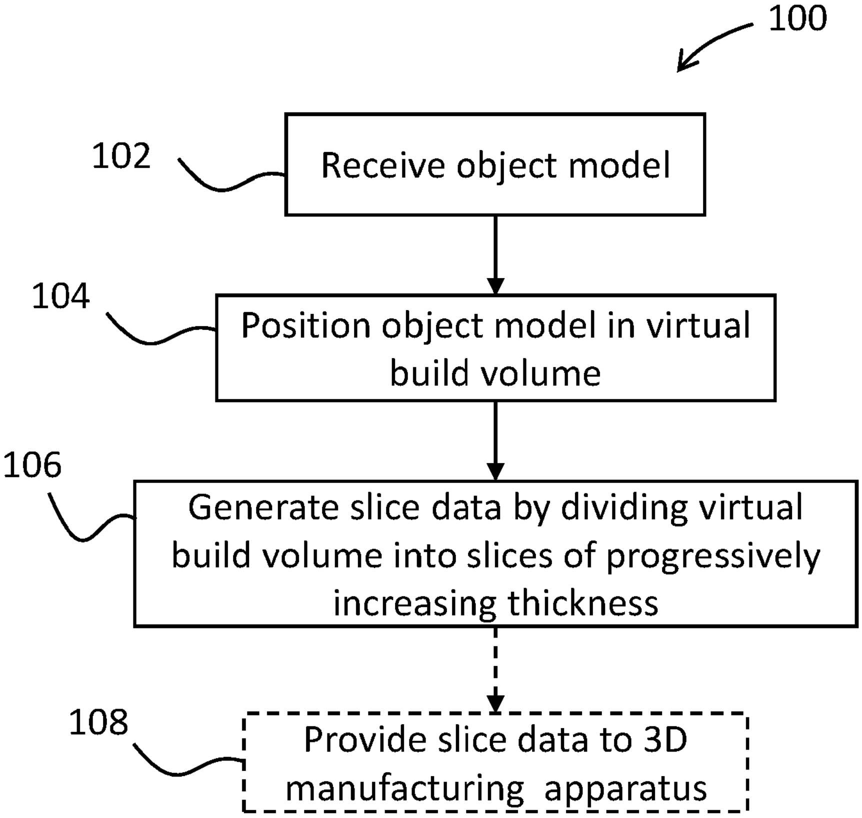

100
102
Receive object model
104
Position object model in virtual build volume
106
Generate slice data by dividing virtual build volume into slices of progressively increasing thickness
108
Provide slice data to 3D manufacturing apparatus

Fig. 1

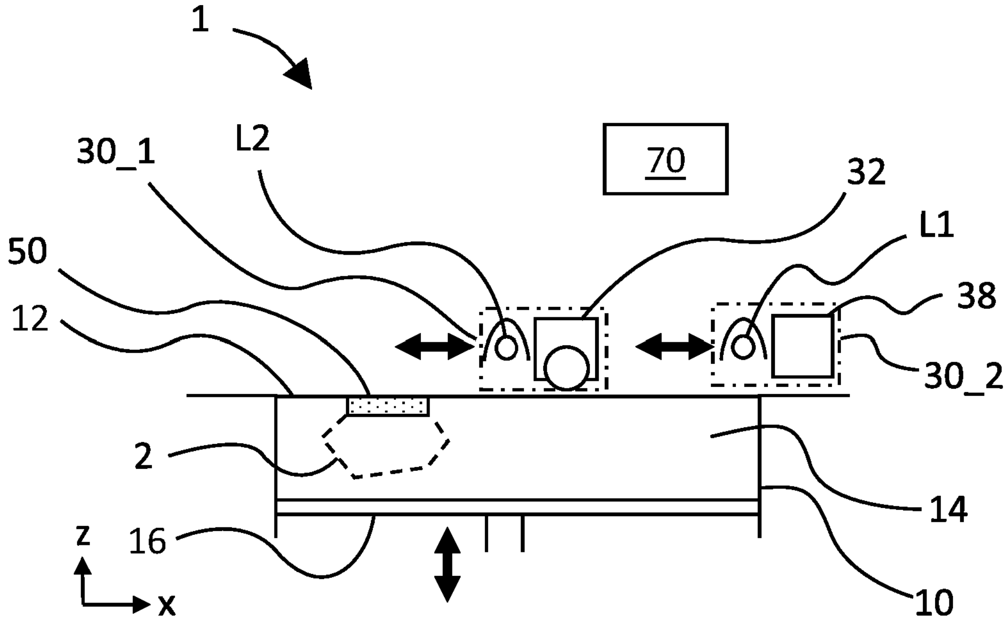

1
30_1
L2
70
32
L1
38
50
12
30_2
2
14
z
16
x
10

Fig. 2

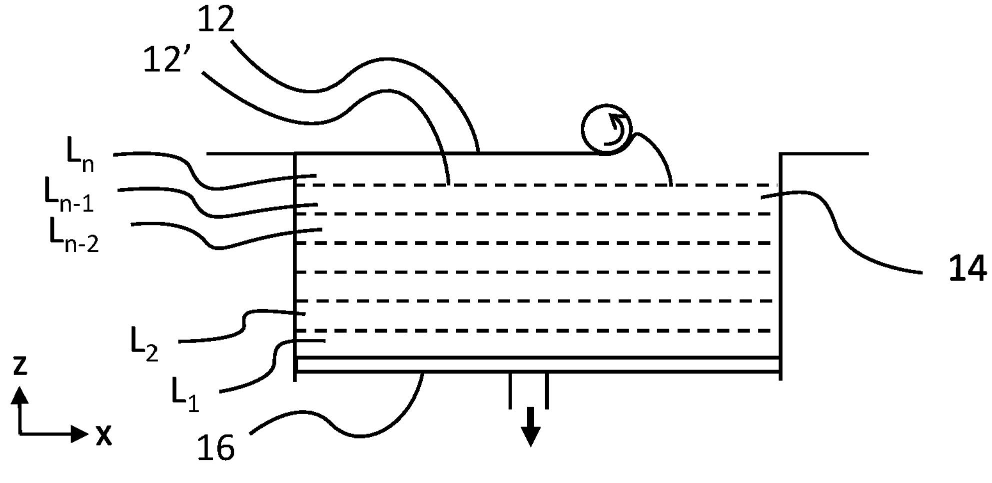
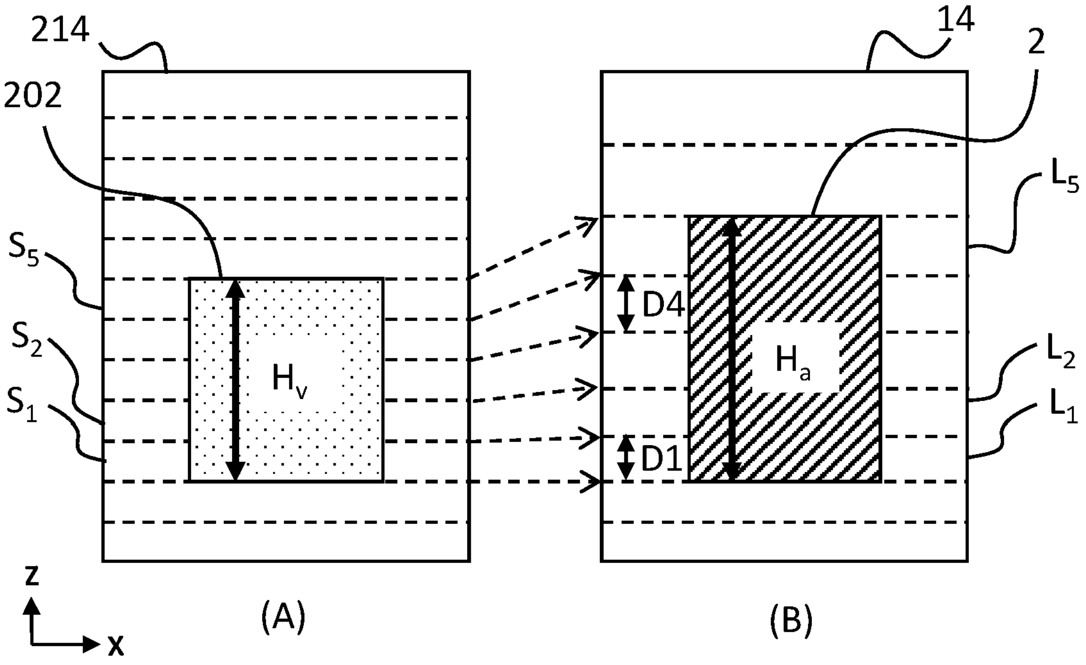

12
12'
L_n
L_{n-1}
L_{n-2}
14
L_2
z
L_1
x
16

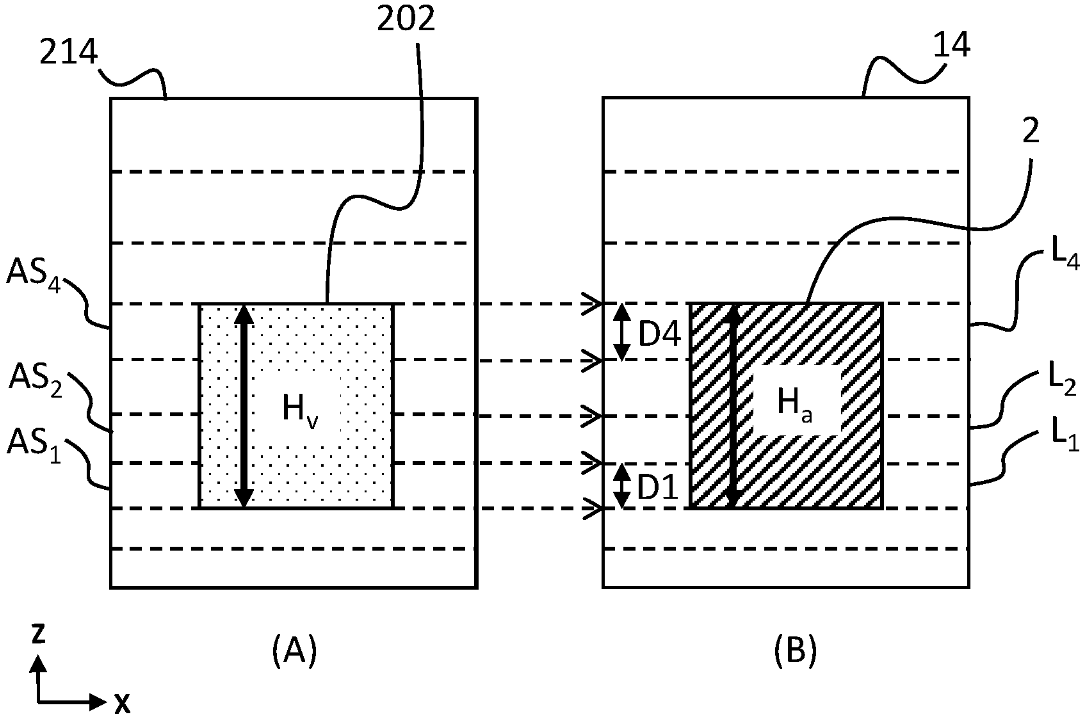
Fig. 3



(A)

(B)

Fig. 4



(A)

(B)

Fig. 5

METHOD FOR GENERATING SLICE DATA FOR THE LAYERWISE MANUFACTURE OF 3D OBJECTS FROM PARTICULATE MATERIAL

FIELD OF THE INVENTION

The present disclosure relates to a method for generating slice data for the layer-by-layer manufacture of three-dimensional (3D) objects from particulate material. The method might find particular benefit in applications requiring accuracy in object dimensions along the layering direction and may be implemented by a computer.

BACKGROUND

In applications for forming 3D objects from particulate material, such as powder bed fusion applications like “print and sinter” and laser sintering, an object is formed layer-by-layer from particulate material spread in successive layers across a support. Each successive layer of the object is melted, or partially melted, to fuse or sinter the particulate material over defined regions and, in so doing, to consolidate it, to form a cross section of the 3D object. In the context of particulate polymer materials for example, the process of melting achieves fusion of particles in each layer comprising an object cross section. Powder bed fusion processes require careful compensation against departures from the intended object dimensions to avoid reduced yield for objects requiring high dimensional accuracy, and such compensation methods can be inadequate or inefficient to sufficiently account for aspects of such shrinkage. To ensure that the final size of objects made by powder bed fusion applications is substantially as intended, better compensation methods are needed to provide improved dimensional accuracy of 3D objects.

SUMMARY

Aspects of the invention are set out in the appended independent claims, while particular embodiments of the invention are set out in the appended dependent claims.

The following disclosure describes, in one aspect, a method for generating slice data from a virtual build volume for the layerwise manufacture of one or more objects within an actual build volume, wherein the virtual build volume represents an actual build volume to comprise the one or more objects, the method comprising the steps of: (a) receiving one or more object models representing the one or more objects to be manufactured; (b) positioning the one or more object models in the virtual build volume; (c) generating slice data by dividing the virtual build volume into groups of parallel planar slices stacked in the vertical direction, the vertical direction corresponding to the layering direction of the layers, each slice corresponding to a layer within the actual build volume; wherein each group comprises one or more slices of the same slice thickness and wherein the slice thickness is progressively increased from one group to the next, such that the slice thickness of an upper group is greater than the slice thickness of a lower group with respect to the vertical direction.

In a second aspect, disclosed is a controller for an apparatus for the layer-by-layer manufacture of a 3D object from the particulate material and configured to carry out the method of the first aspect.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference is now directed to the drawings, in which:

Fig. 1 is a flow chart according to the method of the invention;

Fig. 2 is a schematic cross-section of detail of a side view of an apparatus configured to carry out the method according to the invention;

Fig. 3 is a schematic cross-section of ideal layers in the build bed;

Fig. 4A is a schematic cross-section of an ideal sliced virtual build volume;

Fig. 4B is a schematic cross-section of the actual build volume processed according to slice data of Fig. 4A;

Fig. 5A is a schematic cross-section of an adjusted sliced virtual build volume; and

Fig. 5B is a schematic cross-section of the actual build volume processed according to slice data of Fig. 5A.

In the drawings, like elements are indicated by like reference numerals throughout.

DETAILED DESCRIPTION

A 3D object may be built based on slice data representing instructions for a powder bed fusion apparatus for manufacturing the object in an actual build volume. Such slice data is typically generated by positioning an object model corresponding to the object in a virtual build volume that in turn corresponds to the actual build volume of the apparatus. The virtual build volume is then divided into a stack of successive slices that correspond to the stack layers to be processed in the apparatus, where at least some of the layers comprise the data defining the cross sections of the object. An improved method of generating slice data for an apparatus for the layer-wise manufacture of 3D objects from particulate material, such as a powder bed fusion apparatus, will now be described with reference to Figs. 1 to 5B, and that allows the 3D objects to me manufactured to an improved dimensional accuracy in the layering direction. The method will be illustrated, by way of example of a type of powder bed fusion type apparatus, with reference to a print and sinter apparatus, although it may equally apply to a laser sintering apparatus for example.

Turning first to Fig. 2, detail of a schematic cross section of a print and sinter apparatus 1 is illustrated. In a powder bed fusion processes in general, successive layers of particulate material are distributed, each to form a build bed 14 supported on a platform 16. The build bed is progressively built up from individual layers, each new layer forming a build bed surface 12 which is then processed to form cross-section 50 of the object 2. In this context, the reference to the 'build bed surface' is to the surface of the topmost layer of particulate material of the build bed 14. As indicated in Figure 2, the apparatus 1 comprises a build container having walls 10 and a build platform 16 that contain the object(s) within a build volume 14 of particulate material. The build platform 16 is arranged to move vertically along z within the walls 10, to lower or raise the build bed surface 12. The apparatus 1 further comprises, without specifically showing, a reservoir to supply particulate material to a dosing module that doses an amount of fresh particulate material to be distributed across the build volume (build bed) 14, thus forming a new build bed surface 12. Modules for distributing the particulate material and processing each formed layer are provided on one or more carriages 30 that are moveable back and forth above the build bed 14 across the layer; in Fig. 2 the modules for processing each layer are representing features of a print and sinter process. For illustrative purposes, Fig. 2 shows two carriages: a first carriage 30_1 comprising a distribution module 32 for distributing a new layer of particulate material over the build bed 14 to form a new build bed surface 12; and a second carriage 30_2 comprising a droplet deposition module 38 for selectively depositing radiation absorber over the object cross section 50 within the build bed surface 12, and a heat source L1 for heating the object cross section 50 so as to sinter or melt it and form a consolidated cross section of the object within the layer. The distribution module 32 may comprise a roller as indicated, or a blade, for spreading each layer of particulate material over the build bed as the carriage 30_1 is moved across the build bed. The droplet deposition module may comprise one or more printheads for depositing radiation absorbing fluid. The selectivity of the heat source L1 preferentially heating the object cross section 50 versus the surrounding area is achieved by providing the heat source L1 which generates heat with a spectrum of radiation that, at least partially, overlaps with the absorption spectrum of radiation absorbing fluid but that is not significantly absorbed by the areas of particulate material over which radiation absorbing fluid has not been deposited. If the combination of absorber amount deposited over the object cross section and power input to the heat source L1 causes a sufficient energy input to the object cross section 50, the particulate material of the object cross section 50 melts or sinters to fuse and form consolidated particulate material.

A second heat source L2 may be arranged downstream of the distribution module 32, with respect to the direction of distribution, to immediately preheat the layer following distribution. Providing a second moveable preheat source L2 may be an effective way of returning the temperature of the new, and much colder, layer back towards a preheat build bed temperature. This may be done in combination with, or in addition to, operating a stationary overhead heater (not shown) provided above the build bed surface 12. The preheat temperature is typically lower than the melting temperature and higher than the solidification temperature of the particulate material. The particulate material may comprise polymer, for example a polyamide such as PA11 or PA12, or a polypropylene. For polyamide the preheat temperature may range from 180 - 190 °C, and for polypropylene around 120 - 150 °C. Meanwhile the heat source L1 may heat the object cross section 50 to a temperature of 200-210 °C in the case of polyamide and to about 160-170 °C in the case of polypropylene to achieve sintering or melting.

Fig. 3 illustrates a conventional layer process for an object in which the step-down distance of platform 16 is constant for each layer Ln, leading to a series of successive layers of equal height. However, it has been found that the final object may be significantly taller than intended. For example, objects that extend over 100 mm or more in height throughout the build bed 14, or objects of several 10s of millimetres, e.g. 40 mm, placed near the top of a 100 mm or taller build bed, were oversized along the layering direction by several millimetres with respect to their intended height. An object that is around 250 mm tall may be oversized by 2-3 mm or more.

Without being bound to any particular theory, it is thought that at least two factors contribute towards dimensional inaccuracy in the layering direction. The particulate material in the lower layers of the build volume may be compressed or densified by the mass of the upper layers. Furthermore, as the lower regions of the build volume cool, they contract. In combination, these effects progressively contribute to a build bed surface 12 below the anticipated level the taller the supporting build volume becomes. This means that, when the platform 16 is lowered by the intended, fixed layer thickness and a further layer is distributed over the previous build bed surface 12', the new layer is slightly thicker than intended. These shrinkage effects therefore require compensating for to ensure objects are built with sufficient dimensional accuracy in the layering direction.

The effect on actual layer thickness is schematically illustrated in Figs. 4A and 4B. Fig. 4A is a schematic vertical cut through a virtual build volume 214 in which an object model 202 with a square cross section has been positioned. The object model 202 has an intended height H_v, the height representing the layering direction. In a conventional slice data preparation process, the virtual build volume 214 comprising the object model 202 is divided into a stack of parallel horizontal slices S1, S2, ... Sn layered on top of one another along the layering (vertical, or height) direction. The slice planes defining the upper and lower surfaces of the slices are evenly spaced, so that the slices are of equal thickness. The object model 202 as illustrated extends vertically over five slices, S1 to S5, defining an object model height H_v. When this slice data is used in a build process in which the build platform is lowered by a fixed distance for each layer, the resulting object 2 in the actual build volume 14 is taller than expected. This is illustrated schematically in cross section Fig. 4B. The correspondence between the five slices S1 to S5 and five layers L1 to L5 is indicated by the dashed arrows between Figs. 4A and 4B. Due to a progressive increase in layer thickness of layers Ln as result of shrinkage of the underlying build material, which in Figs. 4A and 4B is exaggerated and not to scale, the five object layers L1 to L5 extend over an actual object height H_a that is larger than intended, such that the actual object height H_a is larger the object model height H_v with respect to the z-direction, or layering direction of the slices or layers. The progressive increase in layer thickness is illustrated by Ln becoming progressively thicker, i.e. layer L5 is thicker than layer L4, layer L4 is thicker than layer L3, layer L3 is thicker than layer L2, and so on, such that the error in overall height is compounded as extra layers are added. Without correction, an object dimension in the layering direction is always larger than intended, leading to dimensional inaccuracy and potentially reducing yield if the resulting object requires tight tolerances.

An improved method has been developed for generating slice data that compensates for progressive thickening of the layers Ln. With reference to the flow chart of Fig. 1, the method comprises the steps of:
(a) at block 102, receiving one or more object models 202 representing corresponding one or more objects 2 to be manufactured;
(b) at block 104, placing or positioning the one or more object models 202 in a virtual build volume 214, the virtual build volume 214 representing an actual build volume 14 comprising the one or more objects 2 in an apparatus 1 for the layerwise manufacture of objects;
(c) at block 106, generating slice data by dividing the virtual build volume 214 into groups of slices ASn stacked in the vertical direction, the vertical direction corresponding to the layering direction of the layers, each slice ASn representing a layer Ln of the actual build volume 14; wherein the slice thickness of successive groups of one or more slices is progressively varied. Herein, the thickness is the dimension in the layering direction.
The order of applying the steps of block 104 and 106 may be reversed depending on how the specific process in which the slice data is generated.

The slices may conveniently be planar parallel slices. This means that shrinkage is compensated for in the same way for any location in the plane of the slice, or layer.

The slice thickness in the virtual build volume 214 may be progressively increased such that the slice thickness of an upper group is greater than the slice thickness of a lower group within the virtual build volume 214. A lower group of slices may correspond to a group of layers located nearer the floor of the build chamber 14 compared to an upper group of layers. The slice thickness may be increased non-linearly in the vertical direction, along z, for example to represent the compaction and shrinkage of the actual build volume 214 and particulate material. Furthermore, the slice thickness of the upper group may be more than an intended layer thickness in the actual build volume, and wherein the intended layer thickness is a constant thickness and defines the constant distance by which the platform 16 is lowered before the distribution of each layer. As the build progresses, the actual layer thickness of each new layer increasingly deviates from the intended layer thickness due to compaction and shrinkage of the build material along the vertical direction. The progressive variation or increase in slice thickness from group to group may be represented by an expansion function determined empirically from test objects or based on a model of layer expansion taking into account material properties and process conditions to determine compaction and shrinkage of the build volume.

Each group may comprise one slice, or it may comprise a plurality of slices. This may depend on the actual layer thickness that is distributed in the apparatus, the resolution of the movement of the build platform 16, and the degree of shrinkage of the particulate material in the preceding layers as they cool and/or compact. The compensation may be applied to slices comprising a cross section of the object model, or preferentially it may be applied to all slices, including those that do not comprise a cross section of an object model.

In this way, layer expansion compensation may be applied to the slices dividing the virtual build volume 214, before the object 2 is being built and object oversize in the layering direction may be reduced or substantially prevented. The method as described herein may be a computer implemented method provided by a computer or processor during the preparation of slice data for the apparatus.
At optional block 108, the generated slice data may be provided to the apparatus 1 for the one or more objects to be manufactured. The computer may be remote from the apparatus and the slice data provided to the apparatus by a network link, for example.

Compared to the conventional method of Figs. 4A and 4B, similar illustrations in Figs 5A and 5B, in which like parts are labelled with like numerals, the improved method has the effect that the thickness of adjusted slices ASn becomes progressively thicker along the layering direction (along z). In this way, as can been seen, the object model 202 now extends over only four, adjusted, slices AS1 to AS4 within the virtual build volume 214, where the top-most slice AS4 is thicker than the preceding slice AS3, which is thicker than the preceding slice AS2 and so on. The overall object model 202 dimensions are the same as in Fig. 4A. The thickness of adjusted slices ASn may be the same to or similar to the thickness of corresponding layers Ln, which have a thickness of Dn as indicated for the first and final layer of the object 2 by D1 and D4 as illustrated in Fig. 5. The layer thicknesses Dn may be determined empirically and may be the same or approximating the actual layers thicknesses

Ln in Fig. 4B. When the adjusted slices ASn are used as slice data to build the object 2 in the actual build volume 14, the resulting object 2 is substantially of the intended height H_a, i.e. substantially equal to the object model height H_V. Layers Ln, or groups of layers, within the actual build volume 14 are of progressively increasing thickness along the vertical direction, as can be seen in Fig. 5B from the thickness D4 of the topmost layer L4 of the object 2, which is larger than the thickness D1 of the lowest object layer L1.

For simplicity of illustration, each slice thickness is shown as being varied, i.e. showing groups comprising only one slice each and a corresponding single layer per group. In variants, a plurality of slices of uniform slice thickness may be comprised within some or all groups, the slices in different groups being of a different thickness. This may be necessary where the resolution in movement of the build volume platform does not allow a fine adjustment for each layer. Furthermore, the thickness of the adjusted slices ASn may not be identical to the actual thickness of the corresponding layer in the actual build volume. Instead, it may be an approximation over groups of layers measured from test objects built at different location over the layering direction in the build volume.

The variation may therefore be applied after a certain number of slices, for example once the estimated variation has exceeded a threshold that represents the resolution in platform movement. The number of slices in each group of slices may be different from group to group, for example where the variation in slice thickness along the vertical direction is non-linear. A group may comprise one or more slices, where the number of slices from group to group may be different. Some groups may comprise a plurality of slices, for example located nearer the floor of the virtual build volume 214, while others, for example located near the top of the virtual build volume, may comprise only one slice.

The variation in thickness of the series of slices within the virtual build volume 214 may be determined empirically from measuring the vertical dimensions of one or more test objects built in the build volume 14 and comparing with the intended vertical dimensions. The test objects may extend over a majority, or over most or all of the available height of the build volume, which may be the maximum available build volume 14 defined by the lowest position, in z, of the build platform 16. More than one test object may be used, for example a series of test objects of different heights and/or built at different locations along x, y and/or z of the build volume 14.

The variation in thickness between the group of slices within the virtual build volume 214 may alternatively be determined from a model or simulation to determine the expansion function, and may be based on at least one of:

- a build parameter such as processing temperature;
- one or more build parameters;
- a characteristic of the one or more object models;
- the cross-sectional area of the one or more object models defined in one or more preceding slices within the virtual build volume;
- the number of preceding slices, and/or the number of preceding slices comprising object model data; and
- a property, such as densification, or of compaction, of the particulate material as a result of being acted upon by the overlying mass of new material.

The expansion function as determined empirically or from a model may thus be a non-linear expansion function, which describes the increase in layer thickness along the layering direction. Based on the determined expansion function of layer thickness increase along z for a fixed increment by which the platform 16 is lowered for each layer, the thickness of stack of slices and the groups of slices may be determined that divide the virtual build volume. In addition, as described above, the movement resolution of the build platform may be taken into account, which determines the transition from one group of slices to the next. In some variants, the division of the virtual build volume 214 may be achieved by the method further comprising, before block 106, for a series of evenly spaced parallel slice planes, adjusting the spacing between the evenly spaced parallel slice planes such that the spacings between adjusted slice planes define the variable slice thickness of the groups of slices, and generating slice data by dividing at step (c) the virtual build volume using the adjusted series of slice planes. The thickness of slices of at least some of the groups may be larger than the spacing between the series of evenly spaced parallel slice planes. The expansion function may be a non-linear expansion function, and the step of adjusting may comprise applying a non-linear expansion function to the vertical locations of the evenly spaced parallel slice planes, the non-linear expansion function representing the inverse of a shrinkage function representing the observed layerwise shrinkage of the build volume during manufacturing.

In variants of the method, the groups of slices stacked in the vertical direction may be groups of parallel planar slices, each slice of the same group being defined by a pair of parallel slice planes separated by a constant distance and wherein the initially constant distance between slices of successive groups is progressively varied along the layering direction, as is schematically in Fig. 5A; however this is not strictly essential; the slices may be defined in a curvilinear system to take account of expansion variation across the plane of the layers. Further variants may apply a stack of curvilinear slice planes.

The above-described methods were found to at least reduce or compensate for the deviation in height of objects from their intended object height, and thus serve to increase yield and accuracy of object being built in an apparatus for the layerwise manufacture of the object from particulate material, wherein the apparatus is configured to carry out the build process steps of:

- lowering the build platform 16 by an or the intended layer thickness;
- distributing a new layer of particulate material over the build platform 16;
- processing the layer according to the slice data of adjusted slices ASn, wherein each layer Ln corresponds to one of the slices ASn of the groups of slices, and wherein layers comprising a cross section of the one or more objects 2 as defined by the slice data are thermally processed to selectively melt the particulate material within the cross section; and
- repeating the build process steps until the one or more objects 2 are complete;

wherein the intended layer thickness is fixed, such that the actual layer thickness Dn for successive groups of layers progressively increases in the layering direction. In other words, the shrinkage of the actual build volume and associated expansion in layers and thus the vertical object size is compensated for at slice level by reducing the number of slices over which the object is being built, while leaving the progressive increase in layer thickness unaffected.

The method and its variants described herein may further provide improved efficiency in the nesting process of object models in the virtual build volume, where nesting means that the position and orientation of the object models is optimised or improved for best use of the build volume. Conventional methods may apply compensation to the actual object models before slicing; this means that the orientation already needs to be determined before compensation to ensure that the compensation is applied along the correct dimension. If any subsequent optimisation is required, the compensation has to be reapplied, which is computationally resource intensive. By applying compensation against vertical layer expansion during the slicing stage, after orientational adjustments are made, the process of preparing slice data may be more efficient.

CLAIMS

1. A method for generating slice data from a virtual build volume for the layerwise manufacture of one or more objects within an actual build volume, wherein the virtual build volume represents an actual build volume to comprise the one or more objects, the method comprising the steps of:

(a) receiving one or more object models representing the one or more objects to be manufactured;

(b) positioning the one or more object models in the virtual build volume;

(c) generating slice data by dividing the virtual build volume into groups of parallel planar slices stacked in the vertical direction, the vertical direction corresponding to the layering direction of the layers, each slice corresponding to a layer within the actual build volume; wherein each group comprises one or more slices of the same slice thickness and wherein the slice thickness is progressively increased from one group to the next, such that the slice thickness of an upper group is greater than the slice thickness of a lower group with respect to the vertical direction.

2. The method of claim 1, wherein the slice thickness is increased non-linearly in the layering direction.

3. The method of claim 1 or 2, wherein the slice thickness of the upper group is more than an intended layer thickness in the actual build volume, and wherein the intended layer thickness is constant.

4. The method of any preceding claim, wherein one or more groups comprises a plurality of slices.

5. The method of claim 4, wherein each group groups comprises a plurality of slices.

6. The method of any preceding claim, wherein one or more slices represent blank layers not comprising a cross section of the one or more object models.

7. The method of any preceding claim, wherein the increase in slice thickness from group to group is determined empirically from measuring the vertical dimensions of one or more test objects built in the build volume and comparing them with the intended vertical

dimensions to determine an expansion function, wherein the vertical dimension is along the layering direction of the layers.

8. The method of any one of claims 1 to 6, wherein the increase in slice thickness from group to group is determined from a model of the actual build volume based on one or more build parameters to determine an expansion function.

9. The method of claim 7 or 8, wherein the expansion function is a non-linear expansion function describing the progressive increase of layer thickness along the layering direction.

10. The method of claim 8 or 9, wherein the increase in slice thickness from group to group is obtained based on a characteristic of the one or more object models.

11. The method of any preceding claim, wherein the increase in slice thickness from group to group is based on, or further based on, the cross-sectional area of the one or more object models of one or more preceding, lower groups within the virtual build volume.

12. The method of any preceding claim, wherein increase in slice thickness from group to group is based on, or further based on, the number of preceding slices.

13. The method of any preceding claim, wherein the increase in slice thickness from group to group is based on, or further based on, the number of preceding slices comprising object model data.

14. The method of any preceding claim, wherein the increase in slice thickness from group to group is based on, or further based on, a property of the particulate material.

15. The method of any preceding claim, further comprising, before step (c), generating a series of adjusted parallel slice planes by adjusting the spacing between a series of evenly spaced parallel slice planes such that the spacings between adjusted slice planes define the slice thickness of each slice and the number of slices of equal thickness in each group, and dividing at step (c) the virtual build volume using the adjusted series of slice planes to generate the slice data.

16. The method of claim 15, wherein the step of adjusting the vertical locations of the evenly spaced parallel slice planes is based on a or the non-linear expansion function.

17. The method of any preceding claim, further comprising providing the slice data to an apparatus for the layerwise manufacture of the one or more objects.

18. The method of any preceding claim, implemented by a processor.

Application No: GB2208367.9 **Examiner:** Heather Webber
Claims searched: 1 - 18 **Date of search:** 28 November 2022

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-10, 12, 14, 17, 18	WO 2008/120183 A1 (OBJET GEOMETRIES LTD) page 5 lines 8-15, page 16 line 27-page 17 line 6; figures 3-4 and corresponding description
X	1 - 10, 12-14, 17, 18	US2017/0095979 A1 (SASAKI TAKAFUMI) see especially figures 15-20 and corresponding description [0093-0119]
X	1, 2, 4-6, 11, 17, 18	CN107803987 B (HUNAN FARSOON HIGH TECH CO LTD) see paragraphs [0010-0013] and figures

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

B29C; B33Y; G06F

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC

International Classification:

Subclass	Subgroup	Valid From
B29C	0064/386	01/01/2017
B29C	0064/165	01/01/2017
B33Y	0050/00	01/01/2015