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(54) THREE-DIMENSIONAL SHAPING METHOD

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B29K 105/00	(2006.01)

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CPC ***B33Y 10/00*** (2014.12); ***B29C 64/386*** (2017.08); ***B29C 67/0077*** (2013.01); ***B29C 67/0088*** (2013.01); ***B33Y 50/02*** (2014.12); *B22F 3/1055* (2013.01); *B29C 64/153* (2017.08); *B29K 2105/251* (2013.01)

(58) **Field of Classification Search**

CPC B29C 67/77; B33Y 40/00
USPC 425/356, 358, 135, 145, 174.4
See application file for complete search history.

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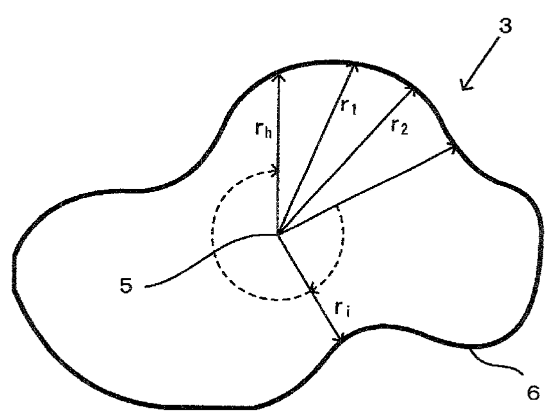
(57) **ABSTRACT**

A three-dimensional shaping method includes a step of forming a powder layer and a step of sintering the powder layer by a moving laser beam or electron beam are alternately repeated to perform a multilayer operation within a container, a plurality of equal-width divided regions are set in a multilayer region along a height direction, and then the number of multilayers N in each of equal-width divided regions which can reflect the degree of variations, according to the degree of variations in the shape of the cross section of a boundary on the upper side and the shape of the cross section of a boundary on the lower side in each of the equal-width divided regions, and the thickness of each multilayer unit in each equal-width divided region is selected, and the coordinates of an outer periphery in each of the cross sections of the number N are set.

21 Claims, 10 Drawing Sheets



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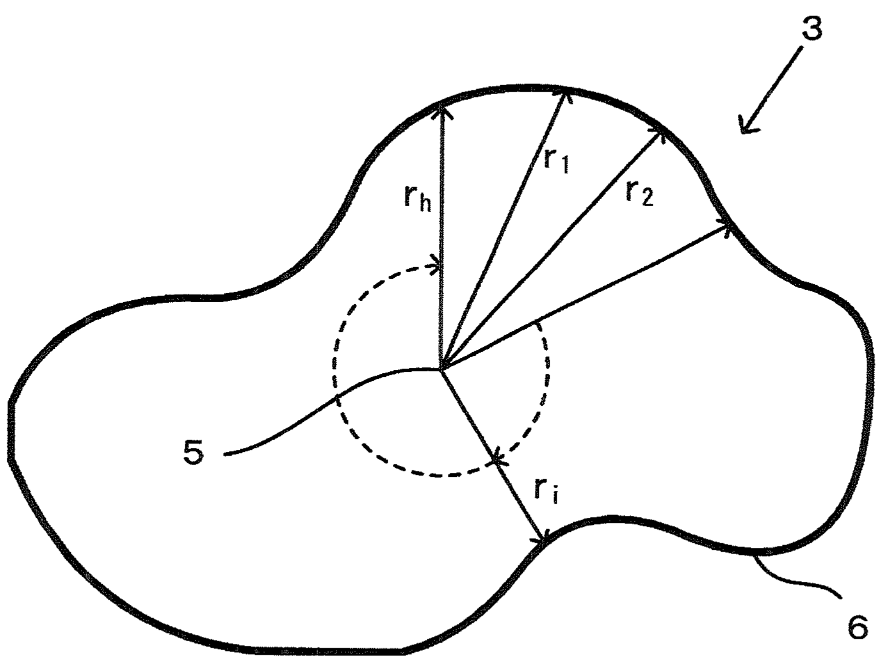
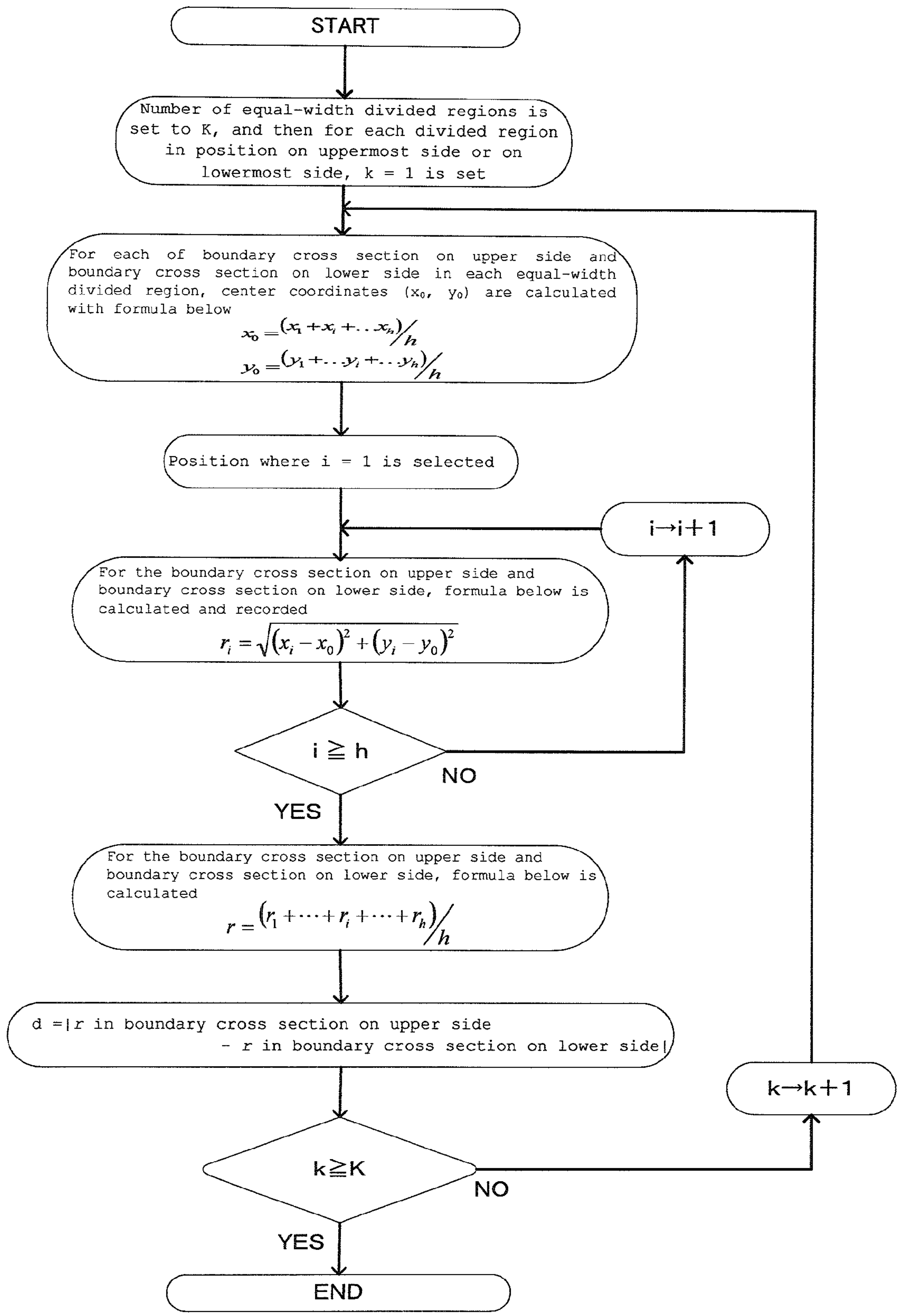
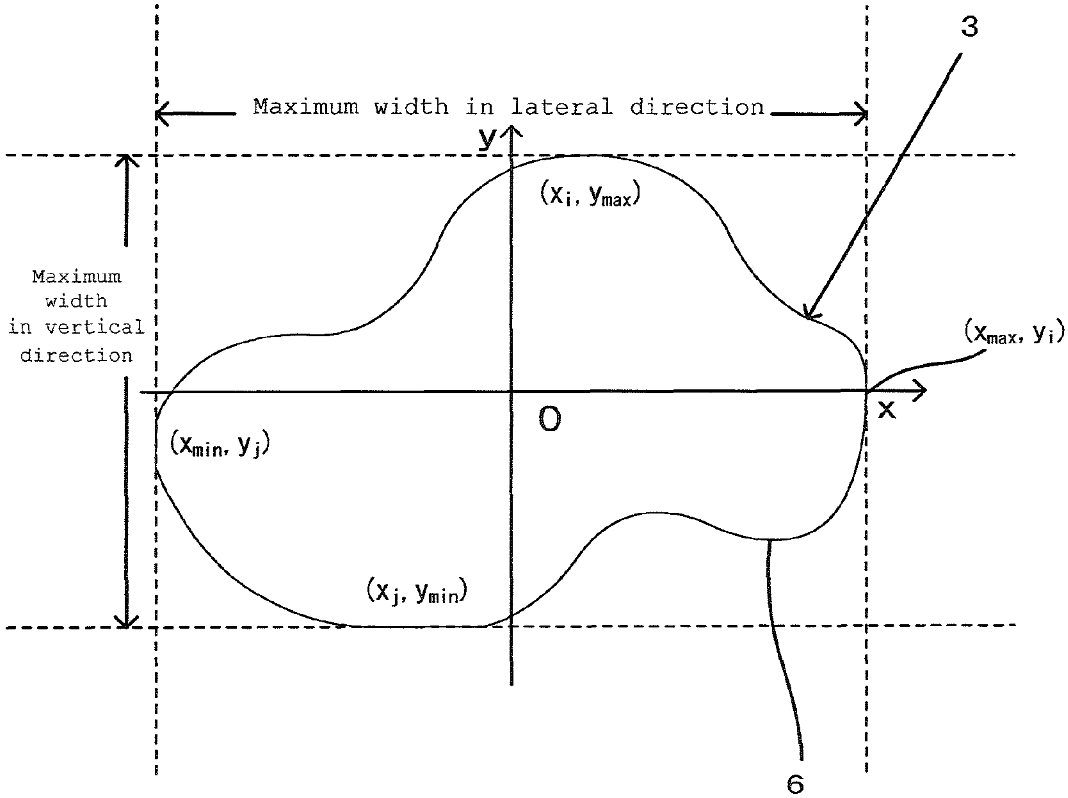
【Fig. 1(a)】



【Fig. 1(b)】

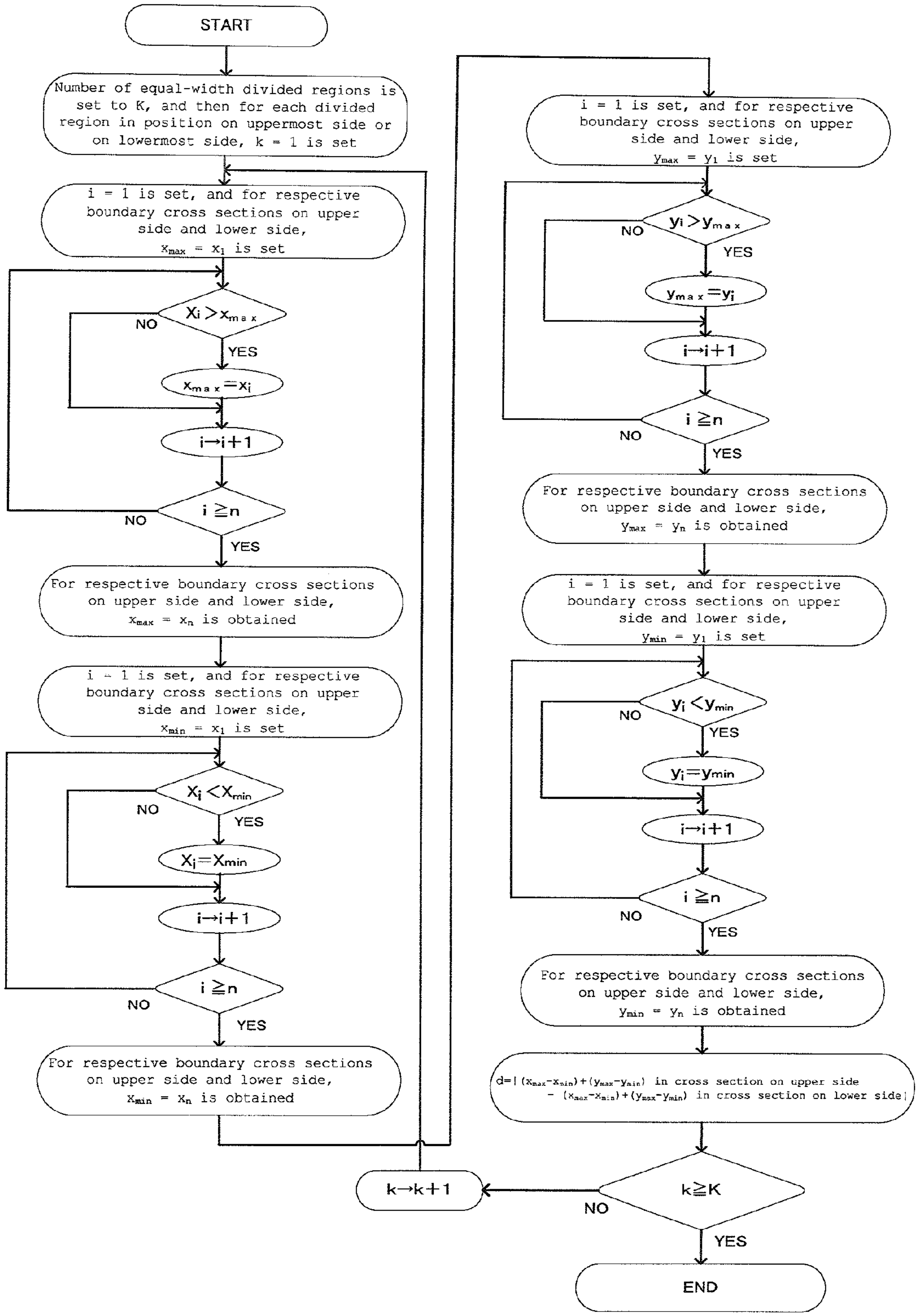

START
Number of equal-width divided regions is set to K, and then for each divided region in position on uppermost side or on lowermost side, k = 1 is set
For each of boundary cross section on upper side and boundary cross section on lower side in each equal-width divided region, center coordinates (x_0, y_0) are calculated with formula below
$x_0 = (x_1 + x_i + .. x_h)/h$
$y_0 = (y_1 + .. y_i + .. y_h)/h$
Position where i = 1 is selected
i→i+1
For the boundary cross section on upper side and boundary cross section on lower side, formula below is calculated and recorded
$r_i = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2}$
i ≧ h
NO
YES
For the boundary cross section on upper side and boundary cross section on lower side, formula below is calculated
$r = (r_1 + \cdots + r_i + \cdots + r_h)/h$
d = |r in boundary cross section on upper side - r in boundary cross section on lower side|
k→k+1
k≧K
NO
YES
END

【Fig. 2(a)】



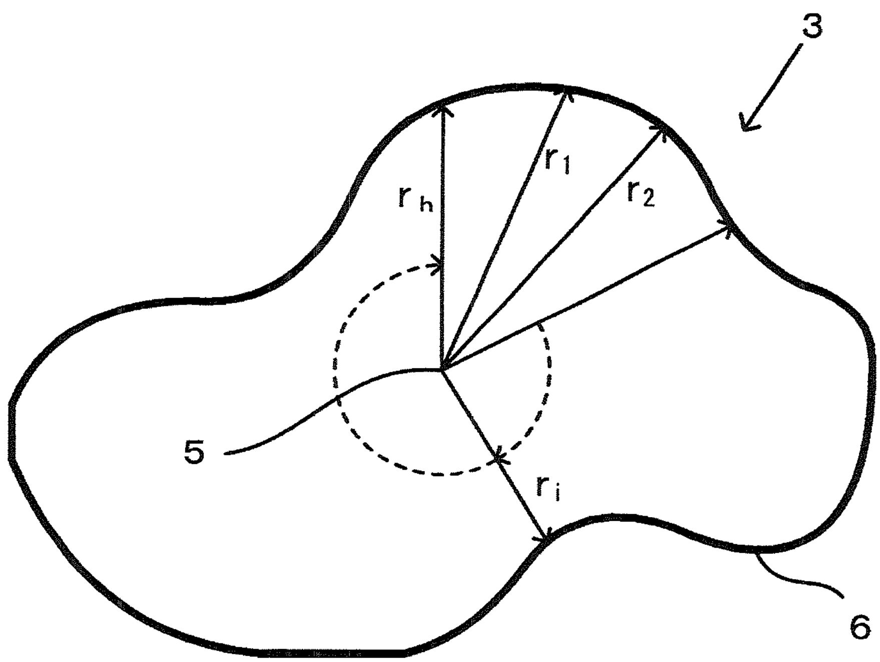
3
Maximum width in lateral direction
y
(x_i, y_{max})
Maximum width in vertical direction
(x_{max}, y_i)
x
O
(x_{min}, y_j)
(x_j, y_{min})
6

【Fig. 2(b)】

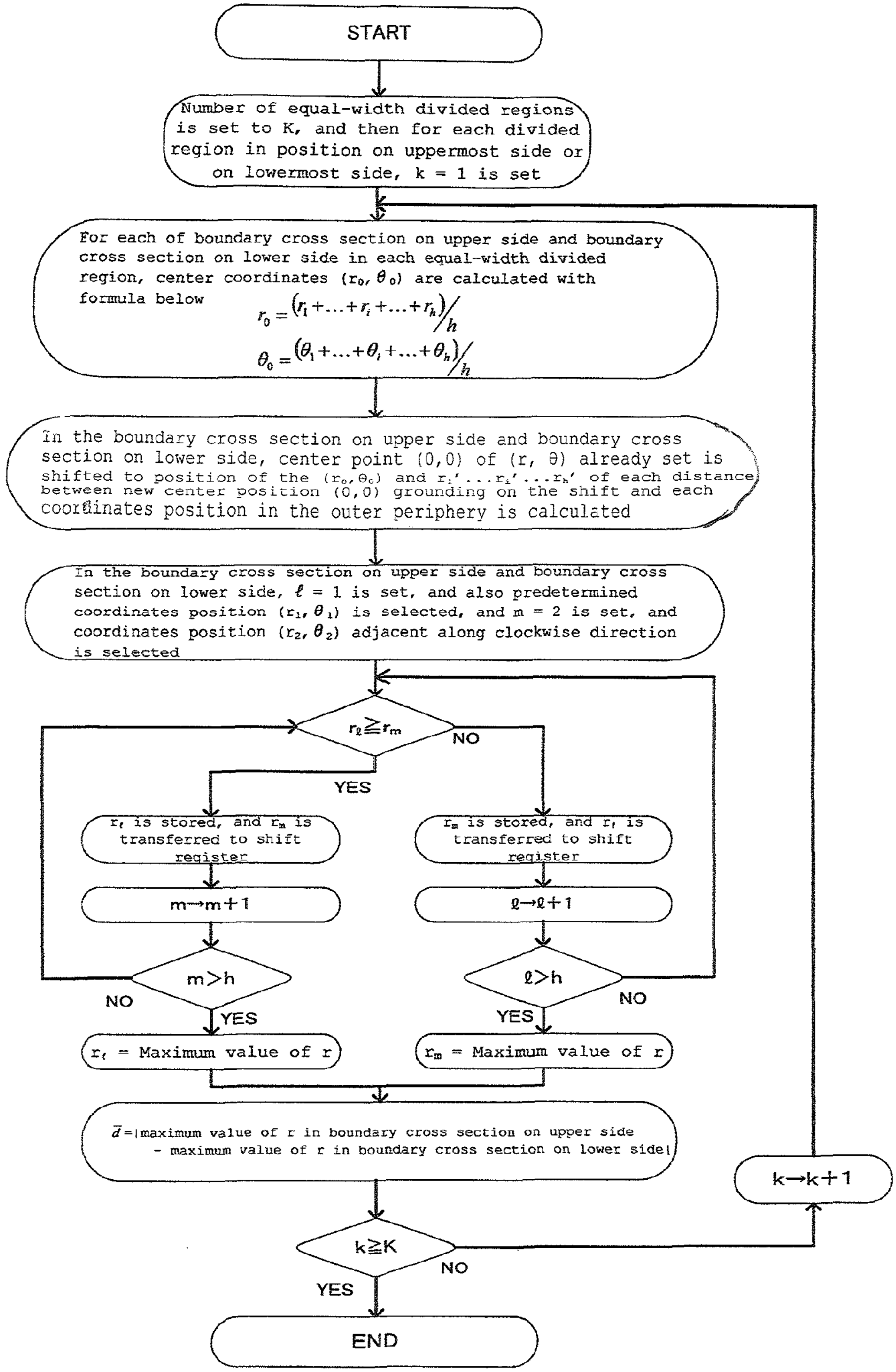


START
Number of equal-width divided regions is set to K, and then for each divided region in position on uppermost side or on lowermost side, k = 1 is set
i = 1 is set, and for respective boundary cross sections on upper side and lower side, x_max = x_1 is set
X_i > x_max
NO
YES
x_max = x_i
i→i+1
i ≧ n
NO
YES
For respective boundary cross sections on upper side and lower side, x_max = x_n is obtained
i = 1 is set, and for respective boundary cross sections on upper side and lower side, x_min = x_1 is set
X_i < X_min
NO
YES
X_i = X_min
i→i+1
i ≧ n
NO
YES
For respective boundary cross sections on upper side and lower side, x_min = x_n is obtained
i = 1 is set, and for respective boundary cross sections on upper side and lower side, y_max = y_1 is set
y_i > y_max
NO
YES
y_max = y_i
i→i+1
i ≧ n
NO
YES
For respective boundary cross sections on upper side and lower side, y_max = y_n is obtained
i = 1 is set, and for respective boundary cross sections on upper side and lower side, y_min = y_1 is set
y_i < y_min
NO
YES
y_i = y_min
i→i+1
i ≧ n
NO
YES
For respective boundary cross sections on upper side and lower side, y_min = y_n is obtained
d=|(x_max-x_min)+(y_max-y_min) in cross section on upper side - (x_max-x_min)+(y_max-y_min) in cross section on lower side|
k≧K
NO
YES
k→k+1
END

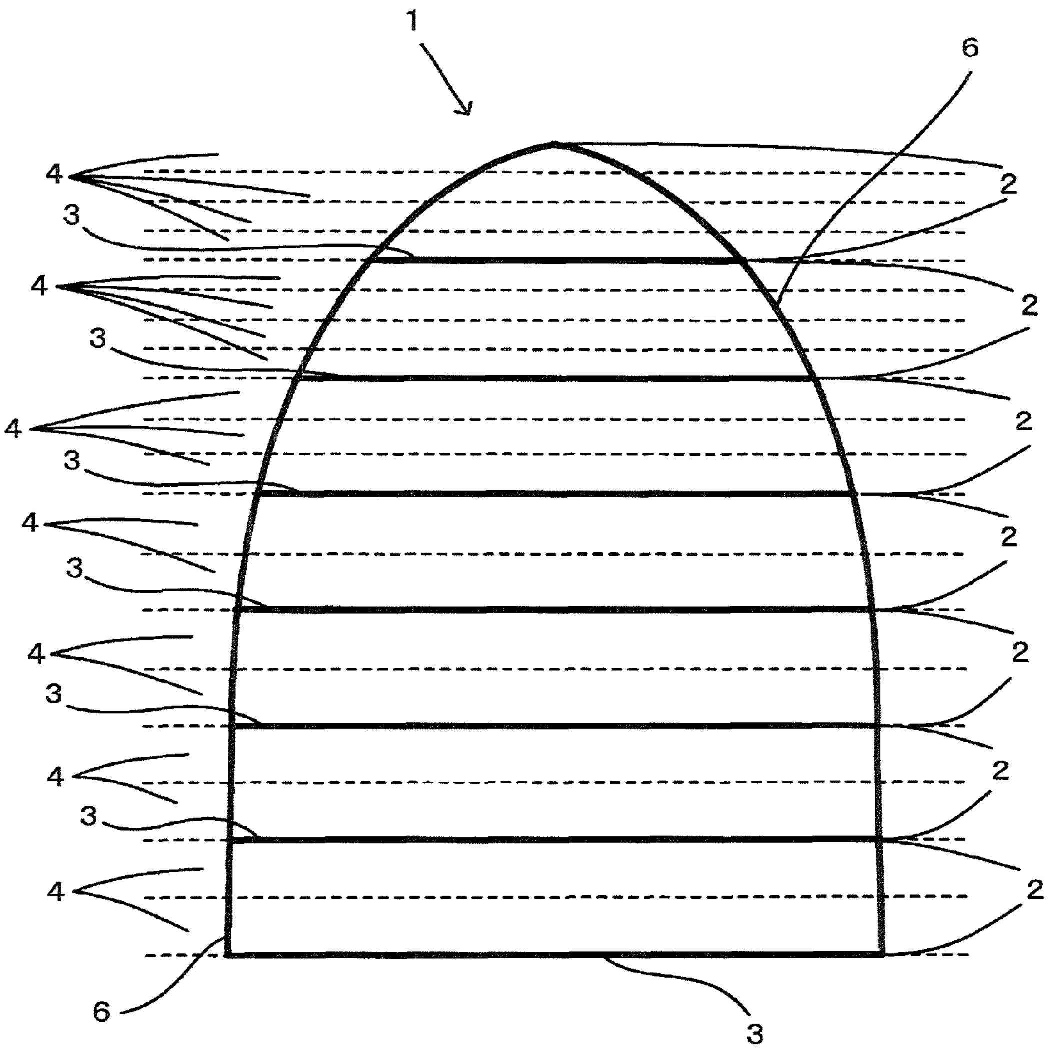
【Fig. 3(a)】



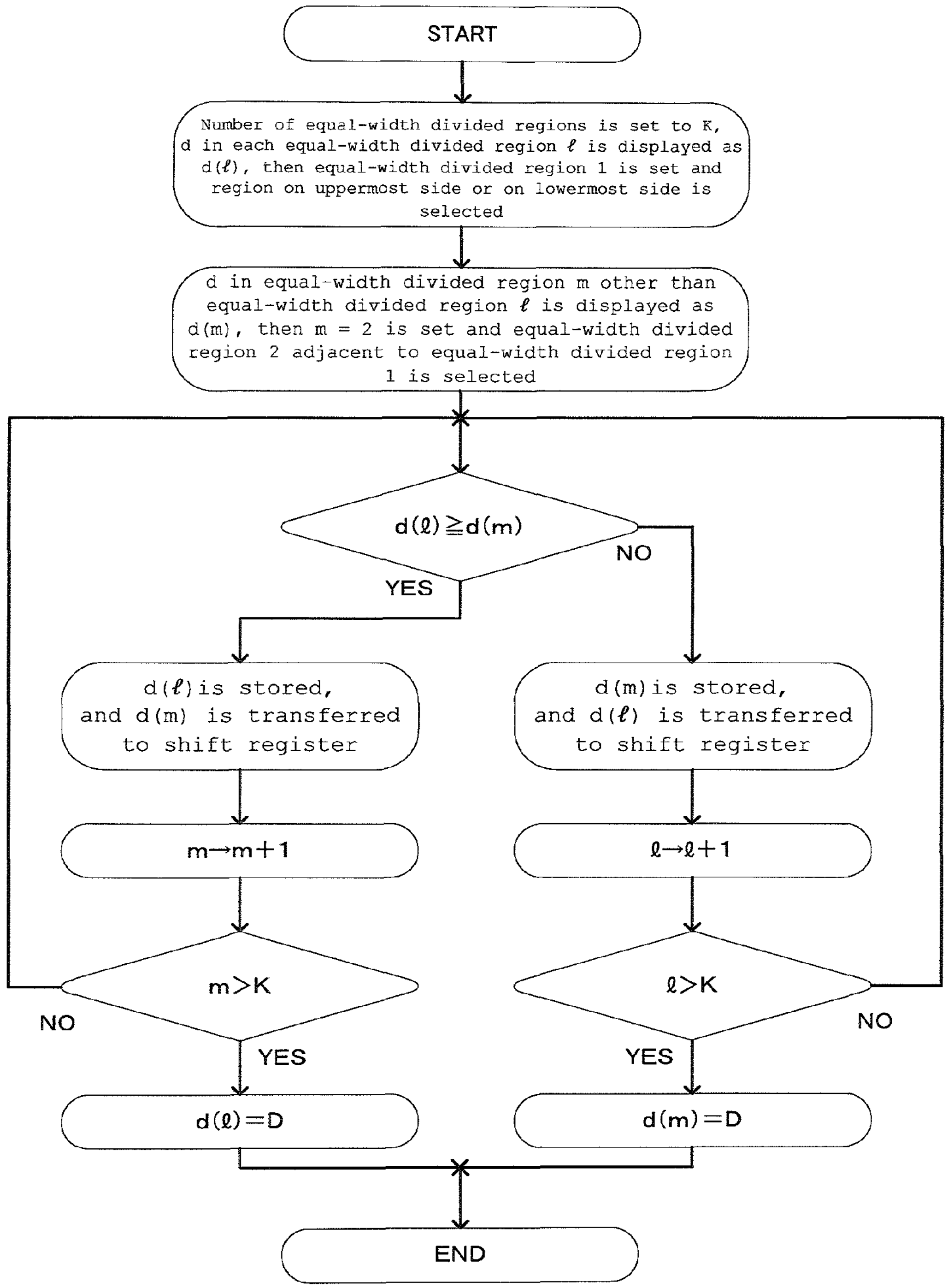
【Fig. 3(b)】


START
Number of equal-width divided regions is set to K, and then for each divided region in position on uppermost side or on lowermost side, k = 1 is set
For each of boundary cross section on upper side and boundary cross section on lower side in each equal-width divided region, center coordinates (r_0, θ_0) are calculated with formula below
$r_0 = (r_1+\ldots+r_i+\ldots+r_h)/h$
$\theta_0 = (\theta_1+\ldots+\theta_i+\ldots+\theta_h)/h$
In the boundary cross section on upper side and boundary cross section on lower side, center point (0,0) of (r, θ) already set is shifted to position of the (r_0, θ_0) and r_1'...r_i'...r_h' of each distance between new center position (0,0) grounding on the shift and each coordinates position in the outer periphery is calculated
In the boundary cross section on upper side and boundary cross section on lower side, ℓ = 1 is set, and also predetermined coordinates position (r_1, θ_1) is selected, and m = 2 is set, and coordinates position (r_2, θ_2) adjacent along clockwise direction is selected
$r_\ell \geqq r_m$
NO
YES
r_ℓ is stored, and r_m is transferred to shift register
r_m is stored, and r_ℓ is transferred to shift register
m→m+1
ℓ→ℓ+1
m>h
ℓ>h
NO
YES
YES
NO
r_ℓ = Maximum value of r
r_m = Maximum value of r
$\bar{d}$ = |maximum value of r in boundary cross section on upper side - maximum value of r in boundary cross section on lower side|
k→k+1
k≧K
NO
YES
END

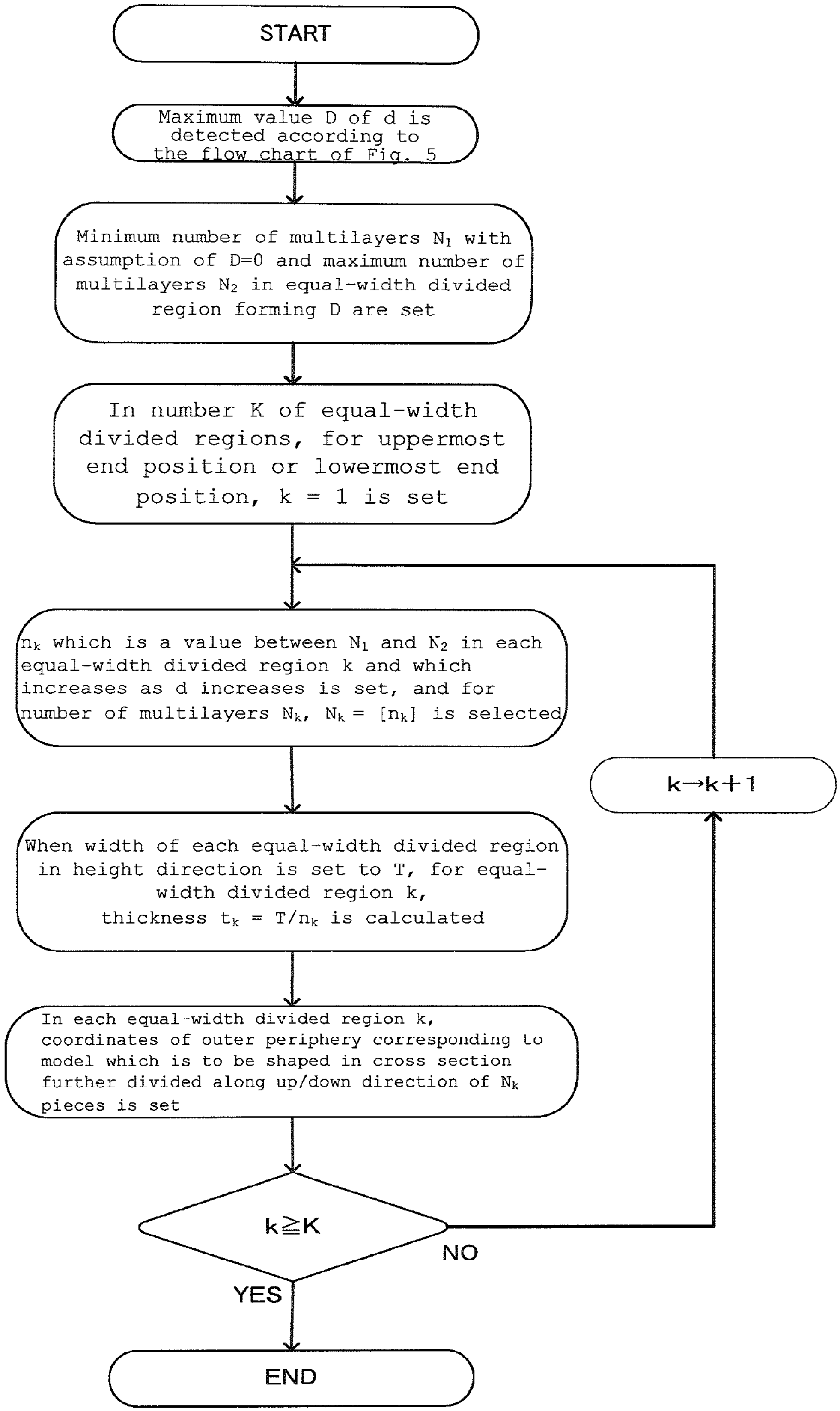
【Fig. 4】



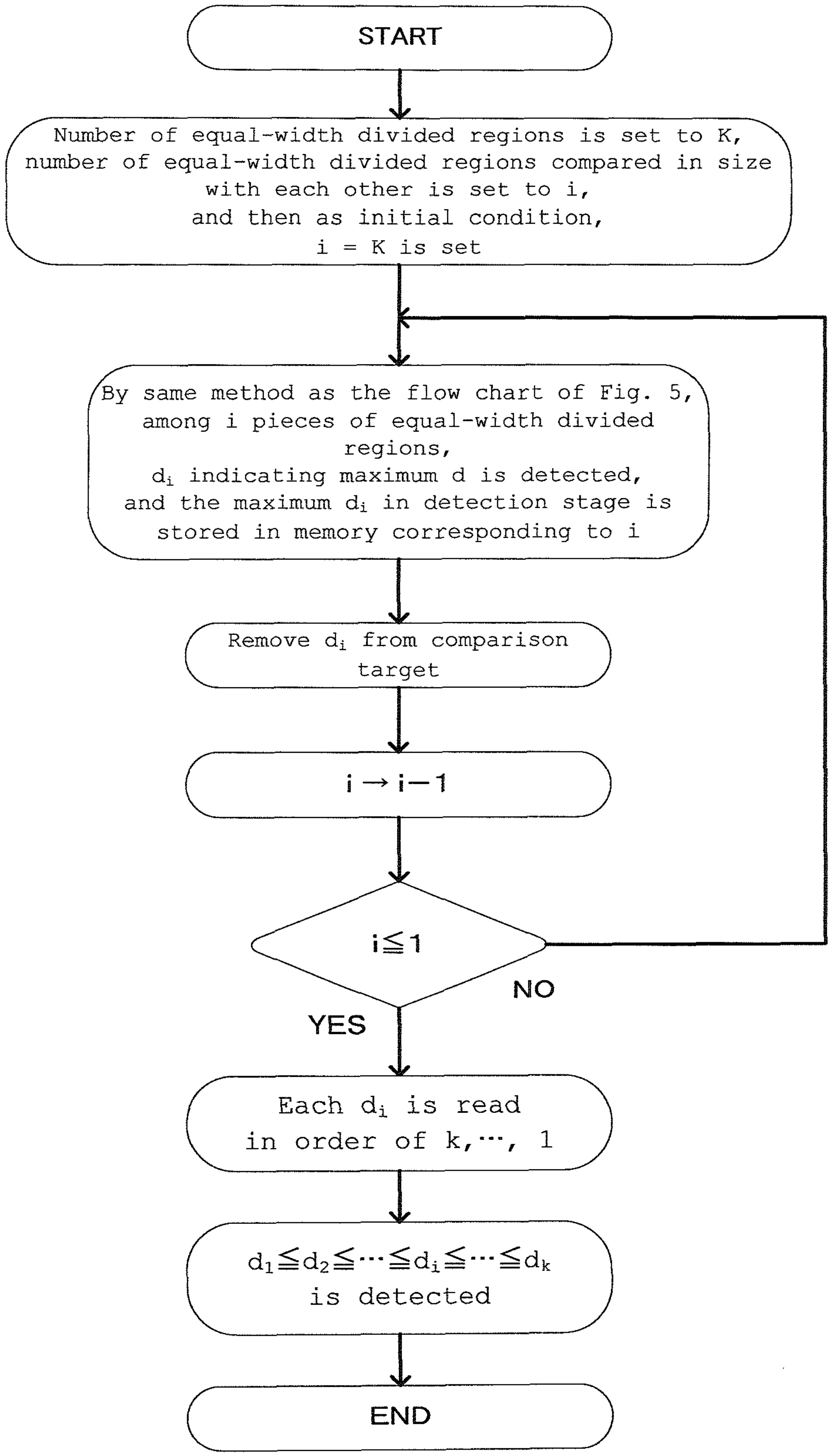
【Fig. 5】


START
Number of equal-width divided regions is set to K, d in each equal-width divided region ℓ is displayed as d(ℓ), then equal-width divided region 1 is set and region on uppermost side or on lowermost side is selected
d in equal-width divided region m other than equal-width divided region ℓ is displayed as d(m), then m = 2 is set and equal-width divided region 2 adjacent to equal-width divided region 1 is selected
d(ℓ)≧d(m)
NO
YES
d(ℓ) is stored, and d(m) is transferred to shift register
d(m) is stored, and d(ℓ) is transferred to shift register
m→m+1
ℓ→ℓ+1
m>K
ℓ>K
NO
YES
YES
NO
d(ℓ)=D
d(m)=D
END

【Fig. 6】


START
Maximum value D of d is detected according to the flow chart of Fig. 5
Minimum number of multilayers N1 with assumption of D=0 and maximum number of multilayers N2 in equal-width divided region forming D are set
In number K of equal-width divided regions, for uppermost end position or lowermost end position, k = 1 is set
nk which is a value between N1 and N2 in each equal-width divided region k and which increases as d increases is set, and for number of multilayers Nk, Nk = [nk] is selected
When width of each equal-width divided region in height direction is set to T, for equal-width divided region k, thickness tk = T/nk is calculated
In each equal-width divided region k, coordinates of outer periphery corresponding to model which is to be shaped in cross section further divided along up/down direction of Nk pieces is set
k≧K
NO
YES
k→k+1
END

【Fig. 7】


START
Number of equal-width divided regions is set to K, number of equal-width divided regions compared in size with each other is set to i, and then as initial condition, i = K is set
By same method as the flow chart of Fig. 5, among i pieces of equal-width divided regions, d_i indicating maximum d is detected, and the maximum d_i in detection stage is stored in memory corresponding to i
Remove d_i from comparison target
i → i−1
i≦1
NO
YES
Each d_i is read in order of k,⋯, 1
$d_1 \leqq d_2 \leqq \cdots \leqq d_i \leqq \cdots \leqq d_k$ is detected
END

THREE-DIMENSIONAL SHAPING METHOD

TECHNICAL FIELD

The present invention relates to a method of manufacturing a three-dimensional shaped article in which when a step of forming a powder layer and a sintering step using a laser beam or an electron beam on the powder layer are repeated, the thickness of each multilayer unit can be selected.

BACKGROUND ART

In a three-dimensional shaping method, the thickness of each multilayer unit is constant in most cases.

In actuality, in Patent Document 1, although consideration is given to the optimization of the thickness of the outermost surface layer in three-dimensional shaping, the thickness is not changed for each multilayer unit.

However, Patent Document 2 discloses that, when in a multilayer operation in a predetermined stage, a convex portion exceeding the thickness of multilayers is detected, the thickness of multilayers in the subsequent stage is set to exceed the height of the convex portion.

However, in the setting of the thickness as described above, the thickness is not selected based on unified criteria corresponding to the overall shape of a shaped object.

In actual three-dimensional shaping, a variation in the cross-sectional shape of a shaped object in a horizontal direction, that is, a direction perpendicular to a height direction in which a multilayer operation is performed and the thickness of each multilayer unit are closely connected with each other.

Specifically, when the shape of each multilayer cross section is significantly varied along the height direction, the thickness of each multilayer unit is decreased such that the original shape of the shaped object can be accurately realized whereas when only a slight variation in the thickness along the up/down direction is produced, even if the thickness of each multilayer unit is set larger, the original shape of the shaped object does not necessarily become inaccurate.

However, in a conventional technique, no consideration is given to the appropriate setting of the thickness of each multilayer unit according to the variation conditions of the cross section in the horizontal direction along the up/down direction.

PRIOR ART DOCUMENTS

Patent Documents

Patent Document 1: Japanese Published Unexamined Patent Application No. 2013-67036

Patent Document 2: Japanese Published Unexamined Patent Application No. 2015-112752

SUMMARY OF INVENTION

Technical Problem

An object of the present invention is to provide, in a three-dimensional shaping method, a configuration in which the thickness of each multilayer unit is appropriately set according to the degree of variation in the cross section of a shaped object in a horizontal direction along a height direction.

Solution to Problem

In order to achieve the above object, the basic configurations of the present invention are as follows.

(1) A three-dimensional shaping method in which a step of forming a powder layer and a step of sintering the powder layer by application of a moving laser beam or a moving electron beam are alternately repeated to perform a multilayer operation within a container, where a plurality of equal-width divided regions are set in a multilayer region to along a height direction, and then according to following processes, a number of multilayers N in each of the equal-width divided regions is selected, for selecting a thickness of each multilayer unit in each of the equal-width divided regions:

1. a process for calculating, in respective cross sections forming boundaries of both upper and lower sides in the equal-width divided regions of a model which is to be shaped, a center position of each of the cross sections and an average distance from the center position to an outer periphery with a CAM or a computer controller and

calculating, for each of the equal-width divided regions, an absolute value d of a difference between an average distance of the respective cross sections in the boundary on the upper side and an average distance of the respective cross sections in the boundary on the lower side;

2. a process for, when it is assumed that d is 0, setting a minimum number of multilayers N_1, detecting a maximum value D of d and setting a maximum number of multilayers N_2 in the equal-width divided region where the maximum value D is formed;

3. a process for setting an increasing number n as d increases between the minimum value N_1 and the maximum value N_2, and selecting a number of multilayers N when N=[n], where [n] is a Gauss symbol indicating a unit of an integer;

4. a process for setting, when in each of the equal-width divided regions in the above 1, equal-width division is further performed with the number of multilayers N in the above 3 along an up/down direction, coordinates of the outer periphery corresponding to the model in the above 1 in each of cross sections of the number N; and

5. a process for controlling, in actual shaping, forming and sintering of the powder layer based on the number of multilayers N selected in the above 3 in each of the equal-width divided regions and movement of a cutting tool in which a position of the coordinates of the outer periphery set in the above 4 is a final cutting position.

(2) A three-dimensional shaping method in which a step of forming a powder layer and a step of sintering the powder layer by application of a moving laser beam or a moving electron beam are alternately repeated to perform a multilayer operation within a container, where a plurality of equal-width divided regions are set in a multilayer region along a height direction, and then according to following processes, a number of multilayers N in each of the equal-width divided regions is selected, for selecting a thickness of each multilayer unit in each of the equal-width divided regions:

1. a process with adopting Cartesian coordinates, that is, (x, y) coordinates and then calculating, in respective cross sections forming boundaries of both upper and lower sides in the equal-width divided regions of a model which is to be shaped, a sum of maximum widths of the respective cross sections in a lateral direction and maximum widths thereof in a vertical direction with a CAM or a computer controller and

calculating, for each of the equal-width divided regions, an absolute value d of a difference between a sum of the respective cross sections in the boundary on the upper side and a sum of the respective cross sections in the boundary on the lower side;

2. a process for, when it is assumed that d is 0, setting a minimum number of multilayers N_1, detecting a maximum value D of d and setting a maximum number of multilayers N_2 in the equal-width divided region where the maximum value D is formed;

3. a process for setting an increasing number n as d increases between the minimum value N_1 and the maximum value N_2, and selecting a number of multilayers N when N=[n], where [n] is a Gauss symbol indicating a unit of an integer;

4. a process for setting, when in each of the equal-width divided regions in the above 1, equal-width division is further performed with the number of multilayers N in the above 3 along an up/down direction, coordinates of the outer periphery corresponding to the model in the above 1 in each of cross sections of the number N; and

5. a process for controlling, in actual shaping, forming and sintering of the powder layer based on the number of multilayers N selected in the above 3 in each of the equal-width divided regions and movement of a cutting tool in which a position of the coordinates of the outer periphery set in the above 4 is a final cutting position.

(3) A three-dimensional shaping method in which a step of forming a powder layer and a step of sintering the powder layer by application of a moving laser beam or a moving electron beam are alternately repeated to perform a multi-layer operation within a container, where a plurality of equal-width divided regions are set in a multilayer region along a height direction, and then according to following processes, a number of multilayers N in each of the equal-width divided regions is selected, for selecting a thickness of each multilayer unit in each of the equal-width divided regions:

1. a process with adopting rotational coordinates, that is, (r, θ) coordinates and then calculating, in respective cross sections forming boundaries of both upper and lower sides in the equal-width divided regions of a model which is to be shaped, a center position of each of the cross sections and a maximum distance from the center position to an outer periphery with a CAM or a computer controller and

calculating, for each of the equal-width divided regions, an absolute value d of a difference between a maximum distance of the respective cross sections in the boundary on the upper side and a maximum distance of the respective cross sections in the boundary on the lower side;

2. a process for, when it is assumed that d is 0, setting a minimum number of multilayers N_1, detecting a maximum value D of d and setting a maximum number of multilayers N_2 in the equal-width divided region where the maximum value D is formed;

3. a process for setting an increasing number n as d increases between the minimum value N_1 and the maximum value N_2, and selecting a number of multilayers N when N=[n], where [n] is a Gauss symbol indicating a unit of an integer;

4. a process for setting, when in each of the equal-width divided regions in the above 1, equal-width division is further performed with the number of multilayers N in the above 3 along an up/down direction, coordinates of the outer periphery corresponding to the model in the above 1 in each of cross sections of the number N; and

5. a process for controlling, in actual shaping, forming and sintering of the powder layer based on the number of multilayers N selected in the above 3 in each of the equal-width divided regions and movement of a cutting tool in which a position of the coordinates of the outer periphery set in the above 4 is a final cutting position.

Advantageous Effects of Invention

In the present invention based on the basic configurations (1), (2) and (3), the number of multilayers (N) in each of the equal-width divided regions is set according to a variation in the cross-sectional shape of each of the equal-width divided regions in the boundary in the horizontal direction, that is, the variation in the average distance from the center in the case of the basic configuration (1), the variation in the sum of the maximum widths in the lateral direction and the vertical direction in the Cartesian coordinates in the case of the basic configuration (2) and the variation in the maximum distance from the center position in the rotational coordinates in the case of the basic configuration (3), and the coordinates of the periphery of each of the cross sections based on the appropriate thickness and the number of multilayers (N) are set according to a variation in the surface in each multilayer unit in the horizontal direction, with the result that it is possible to realize the accurate shape of the shaped object.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1**(*a*) is a cross-sectional view, when in a basic configuration (1), a center position and an average distance from the center position to an outer periphery and the absolute value d of a difference between the average distance in the cross sections of the boundaries on the upper side and the average distance in the cross sections of the boundaries on the lower side are calculated, in the boundary of each of equal-width divided regions which is a target of the calculation;

FIG. **1**(*b*) is a flow chart showing, when in the basic configuration (1), the center position and the average distance from the center position to the outer periphery and the absolute value d of a difference between the average distance in the cross sections of the boundaries on the upper side and the average distance in the cross sections of the boundaries on the lower side are calculated, the order of the calculation;

FIG. **2**(*a*) is a cross-sectional view, when in a basic configuration (2), a sum of the maximum width in a lateral direction and the maximum width in a vertical direction and the absolute value d of a difference between the sum in the cross sections of the boundaries on the upper side and the sum in the cross sections of the boundaries on the lower side are calculated, in the boundary of each of equal-width divided regions which is a target of the calculation;

FIG. **2**(*b*) is a flow chart showing, when in a basic configuration (2), the sum of the maximum width in the lateral direction and the maximum width in the vertical direction and the absolute value d of a difference between the sum in the cross sections of the boundaries on the upper side and the sum in the cross sections of the boundaries on the lower side are calculated, the order of the calculation;

FIG. **3**(*a*) is a cross-sectional view, when in a basic configuration (3), a center position and the maximum distance from the center position and the absolute value d of a difference between the maximum distance in the cross sections of the boundaries on the upper side and the maximum distance in the cross sections of the boundaries on the lower side are calculated, in the boundary of each of equal-width divided regions which is a target of the calculation;

FIG. 3(*b*) is a flow chart showing, when in a basic configuration (3), a center position and the maximum distance from the center position and the absolute value d of a difference between the maximum distance in the cross sections of the boundaries on the upper side and the maximum distance in the cross sections of the boundaries on the lower side are calculated, the order of the calculation;

FIG. **4** is a cross-sectional view showing a state where, in a model which is to be shaped, the equal-width divided regions are set;

FIG. **5** shows a flow chart for detecting the maximum value D of d in the process of the 2 in each of the basic configurations (1), (2) and (3);

FIG. **6** shows a flow chart of the processes of the 2 and the subsequent numbers among the processes of the 1 to 4 in each of the basic configurations (1), (2) and (3); and

FIG. **7** shows a flow chart for detecting the order of the size of d in K pieces of equal-width divided regions.

DESCRIPTION OF EMBODIMENTS

As shown in FIG. **4**, the basic configurations (1), (2) and (3) are common in that a plurality of equal-width divided regions **2** are set in the multilayer region **4** along the height region of the shaping.

By the setting of the equal-width divided regions **2** described above, it is possible to select the number of multilayers N in each of the regions and hence select the thickness of the multilayer unit in each of the equal-width divided regions **2**.

On both the upper and lower sides of each of the equal-width divided regions **2**, the boundaries are always present, however, in each of the equal-width divided regions **2**, as a larger variation is produced between the shape of the cross section **3** of the boundary on the upper side and the shape of the cross section **3** of the boundary on the lower side, a large state of variation conditions is produced in the outer periphery **6** along the length direction.

Attention is focused on such a state, and in the basic configurations (1), (2) and (3), the number of multilayers N is selected according to the variation conditions described above.

Specifically, in the case of the basic configuration (1), as described in the process **1**, the average distance of the cross section **3** is selected as a parameter, in the case of the basic configuration (2), the sum of the maximum width of the cross section **3** in the lateral direction and the maximum width thereof in the vertical direction is selected as a parameter and in the case of the basic configuration (3), the maximum distance from the center position **5** is selected as a parameter.

These parameters are selected based on the fact that, in each of the equal-width divided regions **2**, a larger difference of the each parameters is produced between the cross section **3** on the upper side and the cross section **3** on the lower side, a larger variation condition is produced among respective parameters in the multilayer cross sections **3** along the height direction.

Consequently, in the basic configuration (1), as the process **1**, in the respective cross sections **3** forming the boundaries of both the upper and lower sides in the equal-width divided regions **2** of a model which is to be shaped, with a CAM or a computer controller, as shown in FIGS. **1**(*a*) and **1**(*b*), the center position **5** of each of the cross sections **3** and the average distance from the center position **5** to the outer periphery **6** are calculated, and

for each of the equal-width divided regions **2**, the absolute value d of a difference between the average distance of the respective cross sections **3** in the boundary on the upper side and the average distance of the respective cross sections **3** in the boundary on the lower side is calculated, and

in the basic configuration (2), the Cartesian coordinates, that is, the (x, y) coordinates are adopted, and then in the respective cross sections **3** forming boundaries of both the upper and lower sides in the equal-width divided regions **2** of a model which is to be shaped, with a CAM or a computer controller, as shown in FIGS. **2**(*a*) and **2**(*b*), the sum of the maximum widths of the respective cross sections **3** in the lateral direction and the maximum widths thereof in the vertical direction are calculated and,

for each of the equal-width divided regions **2**, the absolute value d of a difference between the sum of the respective cross sections **3** in the boundary on the upper side and the sum of the respective cross sections **3** in the boundary on the lower side is calculated, and then

in the basic configuration (3), the rotational coordinates, that is, the (r, θ) coordinates are adopted, and then in the respective cross sections **3** forming the boundaries of both the upper and lower sides in the equal-width divided regions **2** of a model which is to be shaped, with a CAM or a computer controller, as shown in FIGS. **3**(*a*) and **3** (*b*), the center position **5** of each of the cross sections **3** and the maximum distance from the center position **5** to the outer periphery **6** are calculated and,

for each of the equal-width divided regions **2**, the absolute value d of a difference between the maximum distance of the respective cross sections **3** in the boundary on the upper side and the maximum distance of the respective cross sections **3** in the boundary on the lower side is calculated.

Although the calculations of the parameters in the respective cross section **3** are realized with a CAM or a computer controller, when as in the basic configuration (1), the average distance from the center position **5** is selected as the parameter, the parameter can reflect the shape of the cross section **3** extremely accurately, whereas when as in the basic configuration (2), the maximum width in the lateral direction and the maximum width in the vertical direction are selected as the parameters and when as in the basic configuration (3), the maximum distance from the center position **5** is selected as the parameter, it is impossible to deny the fact that the basic configurations (2) and (3) are inferior to the basic configuration (1) in the accurate reflection of the shape of the cross section **3**.

However, in order to calculate the average distance from the center position **5**, it is necessary to calculate the center position **5** on all the point coordinates formed on the outer periphery **6** based on a digital design in the respective cross sections **3** and then to further calculate the distance from the center position **5**, whereas since in a normal three-dimensional shaping method, the Cartesian coordinates, that is, the (x, y) coordinates are adopted, it is inevitably necessary to calculate the average distance based on the Pythagorean theorem.

Even if the rotational coordinates, that is, the (r, θ) coordinates are adopted, and thus it is not necessary to perform the above calculation using the Pythagorean theorem, it is very complicated to calculate the average distance.

Hence, as compared with a case where the actual shaping is immediately realized, the process **1** in the basic configuration (1) is suitable for a case where the shaping is previously realized according to the model of each shaped object **1**.

By contrast, since it does not take much time to calculate the sum in the basic configuration (2) and to calculate the maximum distance in the basic configuration (3), in the actual shaping, the calculation of d can be immediately realized according to each shaped object.

The calculations of the process **1** of the basic configurations (1), (2) and (3) are as shown in the flow charts of FIGS. **1**, **2** and **3**, respectively.

In the flow chart of FIG. **3**(*b*), a size relationship between r_l and r_m is based on a criterion in which the cross section in the boundary on the upper side is common to the cross section in the boundary on the lower side, and this is because it is naturally assumed that the number h of coordinates in the cross section in the boundary on the upper side and the cross section in the boundary on the lower side in each of the equal-width divided regions is set such that the division which is so fine as not to reverse the size relationship between r_l and r_m in the cross section in the boundary on the upper side and the cross section in the boundary on the lower side can be performed.

After each process **1** is performed, the processes **2**, **3** and **4** of each of the basic configurations (1), (2) and (3) are identical one another.

Specifically, in the process **2**, the minimum number of multilayers N_1 with the assumption that d is 0 is set, the maximum number D of d is detected in the flow chart shown in FIG. **5** and the maximum number of multilayers N_2 in the equal-width divided region **2** where the maximum value D is formed is set;

in the process **3**, as d increases between the minimum value N_1 and the maximum value N_2, an increasing number n is set, and then the number of multilayers N is selected by a general formula of N=[n]; and

in the process **4**, in the actual shaping, the formation and sintering of the powder layer based on the number of multilayers N selected in the process **3** are performed in the each of the equal-width divided regions **2**.

Although in the process **2**, with the assumption that d is 0, the minimum number of multilayers N_1 is set, this is because in some shaped objects **1**, a region is present in which at a predetermined height and a predetermined width, the shape of the cross section **3** is not varied according to the height direction.

By contrast, in d of each of the equal-width divided regions **2**, the maximum value D is always present, and in this case, since the largest variation in the shape of the cross section **3** within the equal-width divided region **2** is produced, the maximum number of multilayers N_2 is set.

Although in the process **3**, the number of multilayers N reflecting the size relationship between the minimum value N_1 and the maximum value N_2 is selected, this selection is not particularly limited, and the order of the variations of the shape of the cross section **3** needs to reflect the order of the number of multilayers.

After the selection of the number of multilayers N which is a positive integer as described above, in the basic configurations (1), (2) and (3), as in the process **4**, each of the equal-width divided regions **2** according to the process **1** is further equally divided along the up/down direction into N regions, and then in the process **1** of the equally divided N cross sections **3**, the coordinates of the outer periphery **6** corresponding to a model which is to be shaped are set.

The setting of the coordinates of the outer periphery **6** can be realized by recording the shape of the model described above in the memory of the CAM and then the respective coordinates of the outer periphery regions **6** corresponding to the model described above in the cross section **3** by the further equal-width division of each of the equal-width divided regions **2** into the N regions can be calculated with the CAM.

As a result of the process **4** described above, as in the process **5**, it is possible to control the performance of the forming and sintering of the powder layer based on the number of multilayers N, and the movement of the cutting tool such that the coordinates position of the outer periphery **6** set in the process **4** is the final cutting position.

It is also possible either to previously prepare the processes **1**, **2** and **3** and thereafter perform the actual shaping or to perform the actual shaping from the stage of the process **1**, and in particular, the basic configurations (2) and (3) can be extremely suitable for such a method as described above.

The conditions of the processes **2**, **3**, **4** and **5** are individually as shown in the flow chart of FIG. **6**.

As the selection of the positive integer N in the process **3**, the most typical method is to adopt, as the number of multilayers N, the arithmetic mean between the minimum value N_1 and the maximum value N_2 indicated below.

$$N = \left[\left(1 - \frac{d}{D}\right)N_1 + \left(\frac{d}{D}\right)N_2\right] \quad \text{[Formula 1]}$$

As the selection of the number of multilayers N described above, in addition to the arithmetic mean, the geometric mean between the minimum value N_1 and the maximum value N_2 indicated below can also be adopted.

$$N = \left[N_1^{\left(1-\frac{d}{D}\right)} \cdot N_2^{\left(\frac{d}{D}\right)}\right] \quad \text{[Formula 2]}$$

Even in the case of the geometric mean described above, as in the case of the arithmetic mean, the variation in the shape of the cross section **3** in each of the equal-width divided regions **2** can be accurately reflected.

As the selection of the number of multilayers N, a medium value of the arithmetic mean and the geometric mean can also be adopted.

Specifically, preferably, a and b are positive numbers, and moreover a+b=1 is selected, and then the calculation of N=a·(N produced by arithmetic mean)+b·(N produced by geometric mean) or the calculation of N=(N produced by arithmetic mean)^a·(N produced by geometric mean)^b may be performed.

Besides the arithmetic mean or the geometric mean described above and a combination thereof, for d in each of the K pieces of equal-width divided regions **2**, the order of $d_1 \leq d_2 \leq \ldots \leq d_i \leq \ldots \leq d_K$ is detected in the flow chart of FIG. **7**, and then, a state reflecting the order of size of d indicated below can also be adopted.

$$N_i = \left[N_1 + \frac{i}{K}(N_2 - N_1)\right] \quad \text{[Formula 3]}$$

A description will be given below according to Examples.

Example 1

Example 1 is characterized in that the amount of laser beam or electron beam applied per unit area is adjusted according to the thickness of each of the multilayers.

In the shaped object **1**, the degree of sintering is adjusted according to the function of each region as a matter of course.

Hence, when the number of multilayers N in each of the equal-width divided regions **2** is varied, and consequently, the thickness of each multilayer unit is varied, in the case where the degree of the application of each beam is the same, as the thickness of the multilayer unit in the multilayer unit is decreased, the degree of sintering is increased, with the result that disadvantageously, the requirement for the function described above is inevitably not satisfied.

In Example 1, in order to avoid such a disadvantage, the degree of sintering is adjusted according to the variation in the thickness, it is made possible to satisfy the requirement for the function in each region.

Example 2

Example 2 is characterized in that when the cross sections **3** of the respective multilayer units are located in the same position in a direction perpendicular to the height direction, as the thickness of each multilayer unit is increased, the amount of radiation applied per unit area is set larger.

In the case of the actual three-dimensional shaped object **1**, some regions where the degree of sintering is the same are present.

In such a case, when in the basic configurations (1), (2) and (3), the number of multilayers N in each of the equal-width divided regions **2** and furthermore the thickness of each multilayer unit are varied, the same degree of sintering is adopted, with the result that on the contrary, it is inevitably impossible to obtain a uniform degree of sintering.

In Example 2, consideration is given to such a condition, and as the thickness of each multilayer unit is increased, the amount of radiation applied per unit area is increased, with the result that it is made possible to realize a uniform degree of sintering.

INDUSTRIAL APPLICABILITY

As is clear from the above description, in the present invention, it is made possible to set the appropriate thickness of each multilayer unit according to the variation in the cross-sectional shape of the shaped object in the up/down direction, and the present invention can be utilized for all three-dimensional shaping.

REFERENCE SIGNS LIST

1: Object which is to be shaped
2: Equal-width divided region
3: Cross section in boundary of equal-width divided regions
4: Each multilayer region
5: Center position
6: Outer periphery

The invention claimed is:

1. A three-dimensional shaping method in which a step of forming a powder layer and a step of sintering the powder layer by application of a moving laser beam and a moving electron beam are alternately repeated to perform a multilayer operation within a container, comprising the steps of:

providing a station including an arrangement for depositing powder and at least one of a laser beam and electron beam for sintering the deposited powder,

setting a plurality of equal-width divided regions in a multilayer region formed by each powder layer along a

height direction by a computer program of one of a CAM and a computer controller,

then selecting a number of multilayers N in each of the equal-width divided regions by the computer program according to a variation in a cross-sectional shape of each of equal-width divided regions, and

selecting a thickness of each multilayer unit in each of the equal-width divided regions by the computer program by the following steps:

1. calculating with Cartesian (x,y) coordinates, in respective cross sections forming boundaries of both upper and lower sides in the equal-width divided regions of a model which is to be shaped, from each coordinate position $(x_1, y_1) \ldots (x_i, y_i) \ldots (x_h, y_h)$ forming an outer periphery of each cross section and recorded in one of the CAM and the computer controller, a center position (x_0, y_0) of each of the cross sections according to:

$$x_0=(x_1+\ldots x_i+\ldots y_h)/h \text{ and} \quad \text{Formula 1:}$$

$$y_0=(y_1+\ldots y_i+\ldots y_h)/h, \quad \text{Formula 2:}$$

calculating and recording with one of a CAM and a computer controller, an average distance r from the center position (x_0, y_0) to each coordinate position $(x_1, y_1) \ldots (x_i, y_i) \ldots (x_h, y_h)$ in the outer periphery according to the following Formulas:

$$r_i=\sqrt{(x_i-x_0)^2+(y_i-y_0)^2} \text{ and} \quad \text{Formula 3:}$$

$$r=(r_1+\ldots+r_i+\ldots+r_h)/h \text{ and} \quad \text{Formula 4:}$$

calculating, for each of the equal-width divided regions, an absolute value d of a difference between an average distance of the respective cross sections in a boundary on the upper side and an average distance of the respective cross sections in a boundary on the lower side;

2. when it is assumed that d is 0, setting a minimum number of multilayers N_1, detecting the maximum value D of d and setting a maximum number of multilayers N_2 in the equal-width divided region where the maximum value D is formed;

3. setting an increasing number n as d increases between the minimum value N_1 and the maximum value N_2, and selecting a number of multilayers N when N=[n], where [n] is a Gauss symbol indicating a unit of an integer and an increasing number n is set between N_1 and N_2 according to the absolute value d increasing;

4. setting, when in each of the equal-width divided regions in the above step 1, an equal-width division is further performed with the number of multilayers N in the above step 3 along an up/down direction, coordinates of the outer periphery corresponding to the model in the above step 1 in each of cross sections of the number N; and

5. controlling a movement of a cutting tool, in actual shaping, forming and sintering of the powder layer based on the number of multilayers N selected in the above step 3 in each of the equal-width divided regions and movement of a cutting tool in which a position of the coordinates of the outer periphery set in the above step 4 is a final cutting position.

2. The three-dimensional shaping method according to claim **1**,

wherein as the number of multilayers is N, further comprising the step of adopting an arithmetic mean between the minimum value N_1 and the maximum value N_2 according to the following Formula 5:

$$N = \left[\left(1 - \frac{d}{D}\right)N_1 + \left(\frac{d}{D}\right)N_2\right].$$

3. The three-dimensional shaping method according to claim **1**,

wherein as the number of multilayers is N, further comprising the step of adopting a geometric mean between the minimum value N_1 and the maximum value N_2 according to the following Formula 6:

$$N = \left[N_1^{\left(1-\frac{d}{D}\right)} \cdot N_2^{\left(\frac{d}{D}\right)}\right].$$

4. The three-dimensional shaping method according to claim **1**,

wherein as the number of multilayers is N, further comprising the step of adopting a medium value of an arithmetic mean between the minimum value N_1 and the maximum value N_2 and a geometric mean between the minimum value N_1 and the maximum value N_2.

5. The three-dimensional shaping method according to claim **1**,

wherein for d in each of K pieces of equal-width divided regions, detecting an order of $d_1 \leq d_2 \leq \ldots \leq d_i \leq \ldots \leq d_K$, and

then, adopting a state reflecting an order of size of d according to the following Formula 7:

$$N_i = \left[N_1 + \frac{i}{K}(N_2 - N_1)\right].$$

6. A three-dimensional shaping method in which a step of forming a powder layer and a step of sintering the powder layer by application of one of a moving laser beam and a moving electron beam are alternately repeated to perform a multilayer operation within a container, comprising the steps of:

providing a station including an arrangement for depositing powder and at least one of a laser beam and electron beam for sintering the deposited powder,

setting a plurality of equal-width divided regions in a multilayer region formed by each powder layer along a height direction by a computer program of one of a CAM and a computer controller,

then selecting a number of multilayers N in each of the equal-width divided regions by the computer program according to a variation in a sum of maximum widths in a lateral direction and a vertical direction in Cartesian coordinates, and

selecting a thickness of each multilayer unit in each of the equal-width divided regions by the computer program by the following steps:

1. adopting Cartesian (x, y) coordinates and then calculating, in respective cross sections forming boundaries of both upper and lower sides in the equal-width divided regions of a model which is to be shaped, a sum of maximum widths of the respective cross sections in a lateral direction and maximum widths thereof in a vertical direction with one of the CAM and the computer controller and calculating, for each of the equal-width divided regions, an absolute value d of a difference between a sum of the respective cross sections in the boundary on the upper side and a sum of the respective cross sections in the boundary on the lower side;
2. when it is assumed that d is 0, setting a minimum number of multilayers N_1, detecting the maximum value D of d and setting a maximum number of multilayers N_2 in the equal-width divided region where the maximum value D is formed;
3. setting an increasing number n as d increases between the minimum value N_1 and the maximum value N_2, and selecting a number of multilayers N when N=[n], where [n] is a Gauss symbol indicating a unit of an integer and an increasing number n is set between N_1 and N_2 according to the absolute value d increasing;
4. setting, when in each of the equal-width divided regions in the above step 1, an equal-width division is further performed with the number of multilayers N in the above step 3 along an up/down direction, coordinates of the outer periphery corresponding to the model in the above step 1 in each of cross sections of the number N; and
5. controlling a movement of a cutting tool, in actual shaping, forming and sintering of the powder layer based on the number of multilayers N selected in the above step 3 in each of the equal-width divided regions and movement of a cutting tool in which a position of the coordinates of the outer periphery set in the above step 4 is a final cutting position.

7. The three-dimensional shaping method according to claim **6**,

wherein as the number of multilayers is N, further comprising the step of adopting an arithmetic mean between the minimum value N_1 and the maximum value N_2 according to the following Formula 8:

$$N = \left[\left(1 - \frac{d}{D}\right)N_1 + \left(\frac{d}{D}\right)N_2\right].$$

8. The three-dimensional shaping method according to claim **6**,

wherein as the number of multilayers is N, further comprising the step of adopting a geometric mean between the minimum value N_1 and the maximum value N_2 according to the following Formula 9:

$$N = \left[N_1^{\left(1-\frac{d}{D}\right)} \cdot N_2^{\left(\frac{d}{D}\right)}\right].$$

9. The three-dimensional shaping method according to claim **6**,

wherein as the number of multilayers is N, further comprising the step of adopting a medium value of an arithmetic mean between the minimum value N_1 and the maximum value N_2 and a geometric mean between the minimum value N_1 and the maximum value N_2.

10. The three-dimensional shaping method according to claim **6**,

wherein for d in each of K pieces of equal-width divided regions, detecting an order of $d_1 \leq d_2 \leq \ldots \leq d_i \leq \ldots \leq d_K$, and then, adopting a state reflecting an order of size of d according to the following Formula 10:

$$N_i = \left[N_1 + \frac{i}{K}(N_2 - N_1)\right].$$

11. A three-dimensional shaping method in which a step of forming a powder layer and a step of sintering the powder layer by application one of a moving laser beam and a moving electron beam are alternately repeated to perform a multilayer operation within a container, comprising the steps of:

providing a station including an arrangement for depositing powder and at least one of a laser beam and electron beam for sintering the deposited powder,

setting a plurality of equal-width divided regions in a multilayer region formed by each powder layer along a height direction by a computer program of one of a CAM and a computer controller,

then selecting a number of multilayers N in each of the equal-width divided regions by the computer program according to a variation in a maximum distance from a center position in rotational coordinates, and

selecting a thickness of each multilayer unit in each of the equal-width divided regions by the computer program by the following steps:

1. adopting rotational (r, θ) coordinates, and then calculating, in respective cross sections forming boundaries of both upper and lower sides in the equal-width divided regions of a model which is to be shaped, from each coordinate position $(r_1, \theta_1) \ldots (r_i, \theta_i) \ldots (r_h, \theta_h)$ forming an outer periphery and recorded in one of the CAM and the computer controller, a center position (r_0, θ_0) of each of the cross sections according to:

$$r_0=(r_1+\ldots+r_i+\ldots+r_h)/h \text{ and} \quad \text{Formula 11:}$$

$$\theta_0=(\theta_1+\ldots+\theta_i+\ldots+\theta_h)/h \quad \text{Formula 12:}$$

regarding each distance from the center position (r_0, θ_0) to each coordinate position $(r_1, \theta_1) \ldots (r_i, \theta_i) \ldots (r_h, \theta_h)$ forming the outer periphery,

shifting the already set center position (0, 0) in (r, θ) coordinates to said position (r_0, θ_0),

calculating $r_1' \ldots r_i' \ldots r_h'$ from a new center position (0, 0) grounding on the shift to each coordinate position of the outer periphery, and

selecting a maximum distance from each calculated distance, and

calculating, for each of the equal-width divided regions, an absolute value d of a difference between a maximum distance of the respective cross sections in a boundary on the upper side and a maximum distance of the respective cross sections in a boundary on the lower side;

2. when it is assumed that d is 0, setting a minimum number of multilayers N_1, detecting the maximum value D of d and setting a maximum number of multilayers N_2 in the equal-width divided region where the maximum value D is formed;

3. setting an increasing number n as d increases between the minimum value N_1 and the maximum value N_2, and selecting a number of multilayers N when N=[n],

where [n] is a Gauss symbol indicating a unit of an integer and an increasing number n is set between N_1 and N_2 according to the absolute value d increasing;

4. setting, when in each of the equal-width divided regions in the above step 1, an equal-width division is further performed with the number of multilayers N in the above step 3 along an up/down direction, coordinates of the outer periphery corresponding to the model in the above step 1 in each of cross sections of the number N; and

5. controlling a movement of a cutting tool, in actual shaping, forming and sintering of the powder layer based on the number of multilayers N selected in the above step 3 in each of the equal-width divided regions and movement of a cutting tool in which a position of the coordinates of the outer periphery set in the above step 4 is a final cutting position.

12. The three-dimensional shaping method according to claim **11**,

wherein as the number of multilayers is N, an arithmetic mean between the minimum value N_1 and the maximum value N_2 according to the following Formula 13:

$$N = \left[\left(1 - \frac{d}{D}\right)N_1 + \left(\frac{d}{D}\right)N_2\right].$$

13. The three-dimensional shaping method according to claim **11**,

wherein as the number of multilayers is N, further comprising the step of adopting a geometric mean between the minimum value N_1 and the maximum value N_2 according to the following Formula 14:

$$N = \left[N_1^{\left(1-\frac{d}{D}\right)} \cdot N_2^{\left(\frac{d}{D}\right)}\right].$$

14. The three-dimensional shaping method according to claim **11**,

wherein as the number of multilayers is N, further comprising the step of adopting a medium value of an arithmetic mean between the minimum value N_1 and the maximum value N_2 and a geometric mean between the minimum value N_1 and the maximum value N_2.

15. The three-dimensional shaping method according to claim **11**,

wherein for d in each of K pieces of equal-width divided regions, detecting an order of $d_1 \le d_2 \le \ldots \le d_i \le \ldots \le d_K$, and

then, adopting a state reflecting an order of size of d according to the following Formula 15:

$$N_i = \left[N_1 + \frac{i}{K}(N_2 - N_1)\right].$$

16. The three-dimensional shaping method according to claim **1**

further comprising the step of adjusting an amount of the laser beam or the electron beam applied per unit area according to the thickness of each of the multilayers.

17. The three-dimensional shaping method according to claim **16**, wherein when the cross sections of the respective multilayer units are located in a same position in a direction perpendicular to a height direction, as the thickness of each of the multilayer units is increased, further comprising the step of setting the amount of radiation applied per unit area larger.

18. The three-dimensional shaping method according to claim **6**

further comprising the step of adjusting an amount of the laser beam or the electron beam applied per unit area according to the thickness of each of the multilayers.

19. The three-dimensional shaping method according to claim **18**,

wherein when the cross sections of the respective multilayer units are located in a same position in a direction perpendicular to a height direction, as the thickness of each of the multilayer units is increased, further comprising the step of setting the amount of radiation applied per unit area larger.

20. The three-dimensional shaping method according to claim **11**

further comprising the step of adjusting an amount of the laser beam or the electron beam applied per unit area according to the thickness of each of the multilayers.

21. The three-dimensional shaping method according to claim **20**,

wherein when the cross sections of the respective multilayer units are located in a same position in a direction perpendicular to a height direction, as the thickness of each of the multilayer units is increased, further comprising the step of setting the amount of radiation applied per unit area larger.

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