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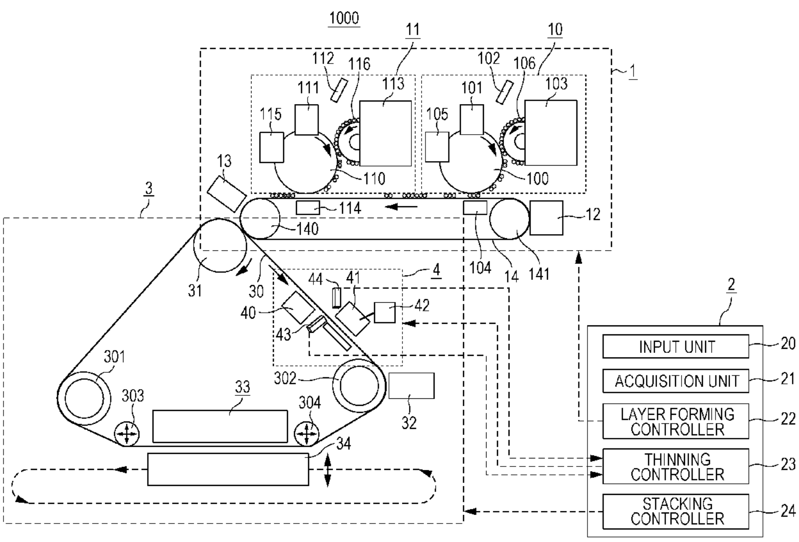
(54) **Title**: FORMING APPARATUS, THREE-DIMENSIONAL FORMING METHOD, AND OBJECT FORMED BY USING THE METHOD



(57) **Abstract**: A forming apparatus (1000), for forming a three-dimensional object by using a forming material, includes a layer forming unit (1) that forms a layer by using the forming material; a transport member (14,30) that transports the layer formed by the layer forming unit, a heating unit (40) that heats the layer supported by the transport member; a pressing unit (41) that presses the layer when the layer is heated by the heating unit or after the layer has been heated by the heating unit; and a stacking unit (3) that stacks the layer pressed by the pressing unit at a stacking position. The forming apparatus is configured so that a temperature of the pressing unit in contact with the layer is lower than a temperature of the transport member.

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Description

Title of Invention: FORMING APPARATUS, THREE-DIMENSIONAL FORMING METHOD, AND OBJECT FORMED BY USING THE METHOD

Technical Field

[0001] The present invention relates to a forming apparatus, a three-dimensional forming method, and an object formed by using the method.

Background Art

[0002] In recent years, forming technologies called additive manufacturing (AM), three-dimensional (3D) printing, rapid prototyping (RP), and the like have been attracting attention. (In the present specification, these technologies will be collectively referred to as the "AM technology".) An example of the AM technology is a technology of forming a three-dimensional object (object) by: slicing three-dimensional shape data of the three-dimensional object into a plurality of slice data; forming layers of a forming material on the basis of the slice data; and successively stacking the layers of the forming material to bond the layers. The AM technology has simplicity in that a die is not necessary and an advantage in that complex shapes can be formed.

Citation List

Patent Literature

[0003] PTL 1: Japanese Patent Laid-Open No. 10-207194

[0004] PTL 1 discloses an apparatus that forms an object by using the AM technology. The apparatus forms an object by forming charged powder on a dielectric body into a sheet by heating and pressing the charged powder, and by stacking the sheet. When a thin film is formed by heating or by heating and pressing a forming material, density is increased because particles of the forming material are melted and joined to each other, and the strength of the thin film is increased.

[0005] In the case where a sheet-shaped layer is formed by heating and pressing a material layer and an object is formed by stacking the sheet-shaped layer, disorder of the sheet-shaped layer may occur when it is being separated from a pressing member. PTL 1 describes that a sheet-shaped layer is formed by heating and pressing a layer by using a heating roller. However, the phenomenon, in which disorder of the sheet-shaped layer may occur when the layer is being separated from the heating roller, is not described in PTL 1.

Summary of Invention

[0006] A forming apparatus according to an aspect of the present invention, for forming a three-dimensional object by using a forming material, includes a layer forming unit that forms a layer by using the forming material; a transport member that transports the layer formed by the layer forming unit; a heating unit that heats the layer supported by the transport member; a pressing unit that presses the layer when the layer is heated by the heating unit or after the layer has been heated by the heating unit; and a stacking unit that stacks the layer pressed by the pressing unit at a stacking position. The forming apparatus is configured so that a temperature of the pressing unit in contact with the layer is lower than a temperature of the transport member.

[0007] Further features of the present invention will become apparent from the following description of embodiments with reference to the attached drawings.

Brief Description of Drawings

[0008] [fig.1]Fig. 1 is a schematic view illustrating the structure of a three-dimensional forming apparatus according to a first embodiment.

[fig.2A]Fig. 2A is a schematic view illustrating the structure of a particle-image forming unit according to the first embodiment.

[fig.2B]Fig. 2B is a schematic view illustrating the detailed structure of a developing device according to the first embodiment.

[fig.3A]Fig. 3A is a schematic view illustrating an example of the structure of a thinning unit according to the first embodiment.

[fig.3B]Fig. 3B is a schematic view illustrating another example of the structure of a thinning unit according to the first embodiment.

[fig.3C]Fig. 3C is a schematic view illustrating another example of the structure of a thinning unit according to the first embodiment.

[fig.3D]Fig. 3D is a schematic view illustrating another example of the structure of a thinning unit according to the first embodiment.

[fig.4]Fig. 4 is a flowchart showing the operation sequence of the three-dimensional forming apparatus according to a first embodiment.

[fig.5]Fig. 5 is a flowchart showing the operation sequence of the thinning unit according to the first embodiment.

[fig.6]Fig. 6 is a schematic view illustrating the structure of a thinning unit according to a second embodiment.

[fig.7A]Fig. 7A is a schematic view illustrating an example of the structure of a thinning unit according to a third embodiment.

[fig.7B]Fig. 7B is a schematic view illustrating another example of the structure of a thinning unit according to the third embodiment.

[fig.8]Fig. 8 is a graph representing the relationship between the viscoelasticity and the temperature of an ABS resin according to the first embodiment.

Description of Embodiments

[0009] Hereinafter, embodiments of the present invention will be described as examples with reference to the drawings. Unless otherwise noted, the scope of the present invention is not limited by the descriptions in the embodiments about, for example, the following matters: the dimensions, the materials, the shapes, the relative positions, and the like of components; and the processes, the control parameters, the target values, and the like of the control operations.

First Embodiment

[0010]

Overall Structure of Three-Dimensional Forming Apparatus

[0011] Referring to Fig. 1, a three-dimensional forming apparatus 1000 according to a first embodiment (hereinafter, referred to as "apparatus 1000") will be described. Fig. 1 is a schematic view illustrating the structure of the three-dimensional forming apparatus 1000 according to the first embodiment.

[0012] The apparatus 1000 is an additive manufacturing (AM) system that forms a sheet-shaped layer by heating and pressing a layer, in which a particulate material is disposed two-dimensionally, and generates a three-dimensional object (object) by stacking the sheet-shaped layer. The apparatus 1000 may be called a 3D printer, a rapid prototyping (RP) system, or the like. For convenience of description, a layer in which a particulate material is disposed two-dimensionally will be referred to as a "particle layer", and a sheet-shaped layer formed by heating and pressing the particle layer will be referred to as a "thin film".

[0013] As illustrated in Fig. 1, the apparatus 1000 includes a layer forming unit 1, a main controller 2, a stacking unit 3, a thinning unit 4, and transport members (intermediate carriers) 14 and 30. The main controller 2 generates multi-layer slice data (section data) of a three-dimensional object (object to be formed) from the three-dimensional shape data of the object, and controls various components of the apparatus 1000. The layer forming unit 1 forms a particle layer, which is composed of a particulate material, by using an electrophotographic process. The thinning unit 4 forms a sheet-shaped thin film by heating and pressing the particle layer. The stacking unit 3 forms the object by successively stacking a plurality of thin films formed by the thinning unit 4.

[0014] In the present embodiment, when a thin film is formed by heating and pressing a particle layer, the temperature of a pressing member 41 may increase due to the heat of the intermediate carrier 30, which transports the particle layer heated by a heating member 40, the heat of the heating member 40, and the like,. Therefore, the thin film may adhere to the pressing member 41, and disorder of the thin film may occur when the thin film is being separated from the pressing member 41. The present embodiment is configured so that the temperature of the pressing member 41 in contact with the thin film is lower than the temperature of the intermediate carrier 30 holding the thin film. With such a structure, the temperature of a thermoplastic forming material is increased and the thermoplastic forming material becomes softer, adherence of the thin film to the pressing member 41 can be suppressed.

[0015] The layer forming unit 1, the main controller 2, the stacking unit 3, and the thinning unit 4 may have different housings or may be disposed in one housing. A structure in which the layer forming unit 1, the main controller 2, the stacking unit 3, and the thinning unit 4 are disposed in different housings has an advantage in that the freedom of the design of the apparatus and the convenience of the apparatus can be improved. To be specific, the freedom of the design of the apparatus and the convenience of the apparatus can be improved, because the components of the apparatus can be easily combined or replaced in accordance with the use, the required performance, the material, the installation space, and the occurrence of malfunctioning of the three-dimensional forming apparatus. On the other hand, a structure in which all the components are disposed in one housing has an advantage in that the size of the entirety of the apparatus can be reduced and the cost of the apparatus can be reduced. The structure of the apparatus 1000 shown in Fig. 1 is only an example, and other structures may be used.

[0016] Particle images are transferred to the intermediate carrier from first and second particle-image forming units 10 and 11 of the layer forming unit 1, thereby forming a particle layer. The intermediate carrier transports the particle layer to the thinning unit 4, and transports a thin film formed by the thinning unit 4 to a stacking position. The intermediate carrier according to the present embodiment includes the first intermediate carrier 14 of the layer forming unit 1 and the second intermediate carrier 30 of the thinning unit 4.

Main Controller

[0017] The structure of the main controller 2 will be described. As illustrated in Fig. 1, the main controller 2 includes, as its functional units, an input unit 20, an acquisition unit 21, a layer forming controller 22, a thinning controller 23, and a stacking controller 24.

[0018] The input unit 20 is a functional unit that receives a three-dimensional shape data of an object to be formed from an external apparatus (such as a personal computer). As the three-dimensional shape data, data output from a 3D CAD system, a 3D modeler, a 3D scanner, or the like can be used. Although the file format of the data is not particularly limited, for example, the stereolithography (STL) file format can be preferably used.

[0019] The acquisition unit 21 is a functional unit that slices the object to be formed, which is represented by the three-dimensional shape data, at a predetermined pitch; calculates the sectional shapes of layers; and generates image data (which is called "slice data"), to be used by the layer forming unit 1 to form an image, on the basis of the sectional shapes. Moreover, the acquisition unit 21 determines the presence/absence of an overhanging portion (a portion protruding into a space) by analyzing the three-dimensional shape data or the slice data of upper and lower layers, and, as necessary, adds an image for a support material to the slice data.

[0020] As will be described below in detail, the layer forming unit 1 according to the present embodiment can form an image by using a plurality of materials. Therefore, data items corresponding to the images to be formed by using the plurality of materials are generated as the slice data. Preferably, the positions and the shapes of the images in the slice data items are adjusted so that images to be formed by using different materials do not overlap. This is because, if the images overlap, the thicknesses of particle layers may vary and the accuracy in the size of the three-dimensional object may be reduced. As the file format of the slice data, for example, multivalued image data (having values representing the types of materials) or multiplane image data (having planes corresponds to the types of materials) can be used.

[0021] The layer forming controller 22 controls a layer forming process of the layer forming unit 1 on the basis of data generated by the acquisition unit 21. The thinning controller 23 controls a thinning process by controlling the timing at which the pressing member 41 of the thinning unit 4 performs pressing, the pressure that the pressing member 41 applies during pressing, the pressing time for which the pressing member 41 performs pressing, the temperature of the heating member 40, the operation of a cooling mechanism 42, and the like. The stacking controller 24 controls a stacking process of the stacking unit 3. Specific control operations performed by the layer forming controller 22, the thinning controller 23, and the stacking controller 24 will be described below.

[0022] The main controller 2 includes an operation unit, a display unit, and a storage unit (which are not shown in Fig. 1). The operation unit receives a command from a user. For example, a user can input power on/off, various setting of the apparatus 1000, and an operation command through the operation unit. The display unit, which has a function of displaying information for a user, displays, for example, various setting screens, error messages, and the operation status. The storage unit stores three-dimensional shape data, slice data, and various setting values.

[0023] The main controller 2 may be a computer including a central processing unit (CPU), a memory, an auxiliary storage device (such as a hard disk or a flash memory), an input device, a display device, and various interfaces. The functions of the input unit 20, the acquisition unit 21, the layer forming controller 22, the thinning controller 23, and the stacking controller 24 are realized by the CPU, which controls necessary devices by reading and executing programs stored in the auxiliary storage device or the like. Some or all of the aforementioned functions may be performed by circuits, such as ASIC or FPGA, or may be executed by another computer by using a technology such as cloud computing or grid computing.

Layer Forming Unit

[0024] Next, the structure of the layer forming unit 1 will be described. The layer forming unit 1 forms a particle layer by using an electrophotographic process. In an electrophotographic process, a desired image is formed through the following steps: uniformly charging a photoconductor (image carrier); exposing the charged photoconductor to light in accordance with image information to form an electrostatic latent image corresponding to the image information on the photoconductor; and forming a developer image on the photoconductor by causing developer particles to adhere to the electrostatic latent image. The principle of the electrophotographic process of a three-dimensional forming apparatus is similar to that of a 2D printer, such as a copier. However, in a three-dimensional forming apparatus, a forming material whose particle diameter is more than ten times larger than those of a toner is used as a developer. Therefore, in some cases, it is not possible to use a process control method or a member structure of a 2D printer in a three-dimensional forming apparatus. In the present embodiment, regarding the particle diameter of a forming material, an appropriate size can be selected.

[0025] As illustrated in Fig. 1, the layer forming unit 1 includes a first particle-image forming unit 10, a second particle-image forming unit 11, a belt cleaning device 12, an image detection sensor 13, and the first intermediate carrier 14. The first particle-image forming unit 10 forms a particle image by using a first particulate material (forming material) 106. The first particle-image forming unit 10 includes a photoconductor (image carrier) 100, a charging device 101 that charges the photoconductor 100, an exposure device 102 that exposes the charged photoconductor 100 to light, and a developing device 103 that forms a particle image by developing an electrostatic latent image formed on the photoconductor 100 by using the first particulate material. The first particle-image forming unit 10 further includes a transfer device 104 that transfers the particle image formed by the developing device 103 to the intermediate carrier 14, and a cleaning device 105 that cleans the photoconductor 100 after the particle image has been transferred. The second particle-image forming unit 11 forms a particle image by a using second particulate material 116. The second particle-image forming unit 11 includes an image carrier 110, a charging device 111, an exposure device 112, a developing device 113, a transfer device 114, and a cleaning device 115, which have the same functions as those of the first particle-image forming unit 10.

[0026] In the present embodiment, a structural material including a thermoplastic resin and the like is used as the first particulate material 106, and a support material having thermoplasticity and water solubility is used as the second particulate material 116. The term "structural material" refers to the material of an object to be formed. In the AM technology, the term "support material" refers to a material that is used, when stacking thin films of a structural material, to form a support portion that supports the structural material so that a part of a thin film superposed on another thin film may not protrude into a space. The support portion is formed so as to be added to a structural material portion when forming a particle layer. The support portion is removed after finishing the stacking step. The structural material and the support material are collectively referred to as a forming material. In a case where a sectional surface does not have an overhanging portion and a support portion is not necessary, the second particle-image forming unit 11 does not form an image. In this case, a particle layer is formed only from the particle image of the structural material.

[0027] As the structural material, for example, polyethylene (PE), polypropylene (PP), ABS, polystyrene (PS), or the like can be used. As the support material, for example, carbohydrate, polyactic acid (PLA), polyvinyl alcohol (PVA), polyethylene glycol (PEG), or the like can be used. The parcel diameter of each material is preferably in the range of 5 μm to 50 μm. In the present embodiment, materials whose particle diameter is about 20 μm are used.

[0028] The first particle-image forming unit 10 and the second particle-image forming unit 11 are disposed along a surface of the first intermediate carrier 14. In Fig. 1, the first particle-image forming unit 10, which forms a particle image of the forming material, is disposed on the upstream side in the transport direction. However, the order of arranging the first particle-image forming unit 10 and the second particle-image forming unit 11 is not limited. The number of particle-image forming units may be more than two or may be increased as necessary in accordance with the number of types of forming materials. For example, when four particle-image forming units are disposed, image formation can be performed by using four structural materials or by using three structural materials and one support material. By using different materials having different colors, stiffnesses, and characteristics, a wider variety of objects can be generated. Such upgradability is one of the advantages of a three-dimensional forming apparatus using an electrophotographic process.

[0029] Hereinafter, the structures of the components of the layer forming unit 1 will be described in detail.

Image Carrier

[0030] Fig. 2A illustrates the structure of the first particle-image forming unit 10. Fig. 2B illustrates the detailed structure of the developing device 103. Only the structure of the first particle-image forming unit 10 will be described here. However, the second particle-image forming unit 11 have the same structure as the first particle-image forming unit 10, except that the material used by the second particle-image forming unit 11 differs from that of the first particle-image forming unit 10.

[0031] The image carrier 100 carries an electrostatic latent image. Here, the image carrier 100 is a photoconductor drum including a metal cylinder, which is made of aluminum or the like, and a photoconductor layer, which is photoconductive, formed on the outer peripheral surface of the metal cylinder. As the photoconductor, an organic photoconductor (OPC), an amorphous silicon photoconductor, a selenium photoconductor, or the like may be used. The type of the photoconductor may be appropriately selected in accordance with the use and the required performance of the apparatus 1000. The image carrier 100 is rotatably supported by a frame (not shown). During an image forming operation, the image carrier 100 is rotated by a motor (not shown) clockwise in Figs. 2A at a constant velocity.

Charging Device

[0032] The charging device 101 uniformly charges the surface of the image carrier 100. In the present embodiment, a non-contact charging method using corona discharge is used. However, another charging method, such as a roller charging method in which a charging roller is brought into contact with the surface of the image carrier 100, may be used.

Exposure Device

[0033] The exposure device 102 exposes the image carrier 100 to light in accordance with image information (slice data) and thereby forms an electrostatic latent image on the surface of the image carrier 100. For example, the exposure device 102 includes a light source, such as a semiconductor laser or a light emitting diode; and a scanning unit including a polygon mirror that rotates at a high velocity and an optical member such as an imaging lens.

Developing Device

[0034] The developing device 103 supplies particles of a forming material, as a developer, to the image carrier 100 and thereby makes the electrostatic latent image be visible (forms a visible image). In the present specification, the visible image formed by the developer will be referred to as a particle image. Fig. 2B illustrates the detailed structure of the developing device 103. The developing device 103 includes a container 1030 that contains the developer, a supply roller 1031 disposed in the container 1030, a developing roller 1032 that carries the developer and supplies the developer to the image carrier 100, and a regulation member 1033 that regulates the thickness of the developer.

[0035] The supply roller 1031 and the developing roller 1032 are rotatably supported by the container 1030 and each rotated counterclockwise in Fig. 2B by a motor (not shown) at a constant velocity when forming an image. Developer particles, which are agitated and charged by the supply roller 1031, are supplied to the developing roller 1032. The regulation member 1033 regulates the layer thickness of the developer so that the layer thickness becomes the same as the thickness of one particle. Subsequently, an electrostatic latent image is developed in a region in which the developing roller 1032 and the image carrier 100 face each other. As the development method, either of a reversal development method, in which a developer is made to adhere to a part of an image carrier that is exposed to light and from which a charge is removed, and a regular development method, in which a developer is made to adhere to the part of an image carrier that is not exposed to light, may be used.

[0036] The developing device 103 may be structured as a so-called developer cartridge, which is removable from the layer forming unit 1. In this case, a user can easily supply or change a developer (a structural material or a support material) by replacing the cartridge. Alternatively, the image carrier 100, the developing device 103, and the cleaning device 105 may be integrated into a cartridge (a so-called process cartridge method). In this case, a user can replace the image carrier.

Transfer Device

[0037] The transfer device 104 transfers a particle image, which is formed on the outer peripheral surface of the image carrier 100, onto the surface of the first intermediate carrier 14. The transfer device 104 is disposed opposite the image carrier 100 with the first intermediate carrier 14 therebetween. The transfer device 104 electrostatically transfers the particle image on the image carrier 100 to the first intermediate carrier 14 by applying a voltage having a polarity opposite to that of the particle image. Transfer from the image carrier 100 to the first intermediate carrier 14 will be referred to as "first-transfer". In the present embodiment, a transfer method using corona discharge is used. However, another transferred method, such as a roller transfer method or a non-electrostatic transfer method, may be used.

Cleaning Device

[0038] The cleaning device 105 cleans the surface of the image carrier 100 by recovering developer particles that are not transferred and remains on the image carrier 100. In the present embodiment, the cleaning device 105 is a blade cleaning device that scrapes off developer particles by using a cleaning blade that is in contact with the image carrier 100 in a direction counter to the rotation direction of the image carrier 100. Alternatively, a brush cleaning device or an electrostatic attraction cleaning device may be used.

First Intermediate Carrier

[0039] The first intermediate carrier 14 is a member to which particle images formed by the first particle-image forming unit 10 and the second particle-image forming unit 11 are transferred. After a particle image of the forming material has been transferred from the first particle-image forming unit 10 on the upstream side, a particle image of the support material is transferred from the second particle-image forming unit 11 on the downstream side so that the positions of these particle images are aligned, and thereby one particle layer is formed on the surface of the first intermediate carrier 14.

[0040] At this time, if the particle images overlap each other on the first intermediate carrier 14, the thickness of the particle layer may vary. Because hundreds to ten thousands of particle layers are stacked to form an object, the variation in the thickness of the particle layer may accumulate and may affect the accuracy in the size of a final product. Accordingly, in the present embodiment, in order to prevent overlapping of particle images, when generating slice data of the materials, the position and the size of the particle image of each forming material is adjusted to reduce the variation in the thickness of the particle layer.

[0041] The first intermediate carrier (first transport member) 14 is an endless transport belt that is made of a material including a polyimide resin or the like. As illustrated in Fig. 1, the first intermediate carrier 14 is looped over a plurality of rollers 140 and 141. A tension roller that is independent from the rollers 140 and 141 may be provided to adjust the tension of the first intermediate carrier 14. At least one of the rollers 140 and 141 is a drive roller, which is driven by a motor (not shown), and rotates the first intermediate carrier 14 counterclockwise in Fig. 1 when forming an image. The roller 140 is a transfer roller that forms a second-transfer region between the roller 140 and a second transfer roller 31 of the stacking unit 3.

Belt Cleaning Device

[0042] The belt cleaning device 12 cleans the surface of the first intermediate carrier 14 by removing a material adhering to the surface. In the present embodiment, the belt cleaning device 12 is a blade cleaning device that scrapes off the material by using a cleaning blade that is in contact with the first intermediate carrier 14 in a direction counter to the direction in which the first intermediate carrier 14 rotates. Alternatively, a brush cleaning device or an electrostatic attraction cleaning device may be used.

First Image Detection Sensor

[0043] The first image detection sensor 13 detects a particle layer carried on the surface of the first intermediate carrier 14. The detection result of the image detection sensor 13 is used, for example, to adjust the position of a particle layer, to control timing of the stacking unit 3, to detect a defect of the particle layer (an undesired image, no image, large variation in the thickness, large displacement of the position of the image, or the like).

Stacking Unit

[0044] Next, the structure of the stacking unit 3 will be described. The stacking unit 3 receives particle layers formed by the layer forming unit 1 from the first intermediate carrier 14, and forms a three-dimensional object by successively stacking the particle layers. As illustrated in Fig. 1, the stacking unit 3 includes the second intermediate carrier 30, the second transfer roller 31, a second image detection sensor 32, a heater 33, and a stage 34. Hereinafter, the structures of the components of the stacking unit 3 will be described in detail.

Second Intermediate Carrier

[0045] The second intermediate carrier (second transport member) 30 is an endless transport belt that is made of a heat-resistant material, such as a metal or a polyimide resin. The second intermediate carrier 30 receives a particle layer formed by the layer forming unit 1 from the first intermediate carrier 14 and transports the particle layer to the thinning unit 4. The thinning unit 4 forms a sheet-shaped thin film by heating and pressing the particle layer that is transported. Subsequently, the second intermediate carrier 30 carries and transports the thin film formed by the thinning unit 4 to a stacking position. The term "stacking position" refers to a position where stacking of thin films is performed (stacking of thin films on a three-dimensional object that is being generated). In the structure shown in Fig. 1, a region in which the second intermediate carrier 30 is located between the heater 33 and the stage 34 corresponds to the stacking position.

[0046] As illustrated in Fig. 1, the second intermediate carrier 30 is looped over the second transfer roller 31 and a plurality of rollers 301, 302, 303, and 304. At least one of the rollers 31, 301, and 302 is a drive roller, which is driven by a motor (not shown), and rotates the second intermediate carrier 30 clockwise in Fig. 1. The rollers 303 and 304 are a pair of rollers that adjust the tension of the second intermediate carrier 30 and that maintain the second intermediate carrier 30 passing through the stacking position to be flat, that is, a thin film that is being stacked to be flat.

Second Transfer Roller

[0047] The second transfer roller 31 transfers a particle layer from the first intermediate carrier 14 to the second intermediate carrier 30. The second transfer roller 31 nips the first intermediate carrier 14 and the second intermediate carrier 30 between the second transfer roller 31 and the roller 140 of the layer forming unit 1, and thereby forms a second-transfer nip between these belts. By applying a bias voltage, which has a polarity opposite to that of the particle layer, to the second transfer roller 31 from a power source (not shown), the particle layer is transferred to the second intermediate carrier 30.

Second Image Detection Sensor

[0048] The second image detection sensor 32 detects a thin film formed by the thinning unit 4. The second image detection sensor 32 detects a thin film formed on the surface of the second intermediate carrier 30. The detection result of the second image detection sensor 32 is used, for example, to adjust the position of the thin film and to control timing at which the thin film is transported to the stacking position.

Heater

[0049] The heater 33 is used to control the temperature of a thin film transported to the stacking position. As the heater 33, for example, a ceramic heater, a halogen heater, or the like can be used. The heater 33 may include a structure for actively decreasing the temperature of a thin film by dissipating heat from the thin film or by cooling the thin film. The lower surface of the heater 33 (facing the belt) is a flat surface that also serves as a guide for the second intermediate carrier 30 passing through the stacking position and a pressing member for applying a uniform pressure to the thin film.

Stage

[0050] The stage 34 is a flat table on which a three-dimensional object is placed. The stage 34 is moved by an actuator (not shown) in a transport direction in which the second intermediate carrier 30 transports a thin film at the stacking position (along the belt surface of the second intermediate carrier 30) and in the direction (vertical direction) perpendicular to the belt surface in the transport direction. The stage 34 nips a thin film, which has been transported by the second intermediate carrier 30 to the stacking position, between the stage 34 and the heater 33 and heats and presses (and, as necessary, cools) the thin film, and thereby transfers the thin film from the second intermediate carrier 30 to the stage 34. A thin film for the first layer is directly transferred onto the stage 34, and thin films for the second and the following layers are stacked on a partially finished object (thin films) on the stage 34.

[0051] When the stage 34 moves at the same velocity as the second intermediate carrier 30 in the transport direction, the pressing time can be increased and thereby a thin film can be more securely joined to the partially finished object. However, this it not a limitation. The stage 34 need not move in the transport direction and may move only in the vertical direction. Thus, in the present embodiment, the heater 33 and the stage 34 constitute a stacking unit that stacks thin films.

Thinning Unit

[0052] The structure of the thinning unit 4 will be described. The thinning unit 4 forms a sheet-shaped thin film by heating and pressing a particle layer, which is carried by the second intermediate carrier 30, before the particle layer reaches the stacking position.

When a thin film is formed by heating or by heating and pressing a forming material, density is increased because particles of the forming material are melted and joined to each other, and the strength of the thin film is increased. Because the surface roughness of the thin film is reduced from that of the particle layer, the thin films can be easily stacked and subsequently can be strongly joined together. Therefore, the strength of the object can be improved. By forming the thin film so as to have a uniform thickness, stacking can be performed more accurately.

[0053] As illustrated in Fig. 1, the thinning unit 4 includes the heating member 40, the pressing member 41, the cooling mechanism 42, a first temperature measurement unit 43, and a second temperature measurement unit 44. Hereinafter, the structures of the components of the thinning unit 4 will be described. Figs. 3A and 3B are schematic views illustrating the structure of the thinning unit 4.

Heating Member

[0054] The heating member 40 heats a particle layer carried by the second intermediate carrier 30 and softens the forming material of the particle layer. The heating member 40 may be, for example, a sheathed heater illustrated in Fig. 3A, and may be structured so as to heat the second intermediate carrier 30 from the back side of the second intermediate carrier 30 (a surface on which a particle layer is not carried). However, this is not a limitation, and other exiting heating units may be used. For example, by using a halogen heater illustrated in Fig. 3B, the second intermediate carrier 30 may be heated from a side on which the particle layer is held in a state in which the heater is not in contact with the particle layer.

Pressing Member

[0055] The pressing member 41 is disposed downstream of the heating member 40 in the transport direction of the particle layer and presses the particle layer that has been heated by the heating member 40. With such a structure, the particle layer can be pressed after having been sufficiently heated. Moreover, the heating member 40 and the pressing member 41 are not in contact with each other with the second intermediate carrier 30 therebetween. Therefore, the pressing member 41 can be cooled easily. Preferably, the surface of the pressing member 41 is made of a material that has heat resistance and high demoldability. For example, a fluorocarbon resin, such as perfluoro alkoxyalkane (PFA) or polytetrafluoroethylene (PTFE), can be used.

[0056] The pressure applied by the pressing member 41 is preferably in the range of 0.3 kgf/cm^2 to 5.0 kgf/cm^2, and more preferably in the range of 0.5 kgf/cm^2 to 3.0kgf/cm^2. If the pressure applied by the pressing member 41 to the particle layer is lower than 0.3kgf/cm^2, the particles of the forming material cannot be sufficiently crushed, and therefore a thin film having a uniform thickness cannot be formed. On the other hand, if the pressure applied by the pressing member 41 is higher than 5.0 kgf/cm^2, the particles of the forming material are excessively crushed, and therefore the accuracy of the stacked object is reduced. Preferably, the pressing time for which the pressing member 41 performs pressing is 10 seconds or shorter. If the pressing time is longer than 10 seconds, the temperature difference between the pressing member 41 and the second intermediate carrier 30 becomes smaller, and therefore the thin film might become disorderly.

[0057] As illustrated in Figs. 3A and 3B, the pressing member 41 includes two pressing rollers 410 and 411 that are disposed with the second intermediate carrier 30 therebetween. Each of the pressing rollers 410 and 411 rotates at a velocity that is the same as the transport velocity of the particle layer transported by the second intermediate carrier 30 in a direction that is the same as the transport direction at a position at which the pressing rollers are in contact with the second intermediate carrier 30. The width of each of the pressing rollers 410 and 411 (the length in a direction perpendicular to the transport direction) is greater than that of the particle layer. The particle layer is pressed while passing through a space between the pressing roller 410 and the pressing roller 411. When the pressing rollers 410 and 411 are used, the contact area in which the pressing roller 410 is in contact with the thin film is small, and therefore disorder of the thin film, which may occur when the thin film is being separated from the pressing roller 410, can be reduced.

Cooling Mechanism

[0058] The cooling mechanism 42 cools the pressing member 41 by, for example, air cooling or water cooling. The cooling mechanism 42 includes a through-member extending through the pressing roller 410, which comes into contact with the particle layer; and a circulation apparatus. The circulation apparatus, which includes a fan or a pump (not shown), cools the pressing roller 410 by causing air, water, a coolant, or the like to flow through the through-member.

First Temperature Measurement Unit

[0059] The first temperature measurement unit 43 is a temperature sensor that measures the temperature of the surface of the second intermediate carrier 30. To be specific, a contact temperature sensor including a thermocouple or the like; a non-contact temperature sensor, such as a radiation temperature sensor; or another known temperature sensor may be used as the first temperature measurement unit 43. Preferably, the temperature of the surface the second intermediate carrier 30 carrying the particle layer thereon is measured by using a non-contact temperature sensor, so that influence on the second intermediate carrier 30 can be avoided. In the present embodiment, the first temperature measurement unit 43 is disposed upstream of the pressing rollers 410 and

411 in the rotation direction of the second intermediate carrier 30. Therefore, the temperature of the second intermediate carrier can be measured after having been heated and before being pressed.

Second Temperature Measurement Unit

[0060] The second temperature measurement unit 44 is a temperature sensor that measures the temperature of the surface of the pressing member 41. In the present embodiment, the second temperature measurement unit 44 measures the temperature of the surface of the pressing roller 410 facing the surface of the second intermediate carrier 30 on which the particle layer is disposed. To be specific, a contact temperature sensor including a thermocouple or the like; a non-contact sensor, such as a radiation temperature sensor; or another known temperature sensor is used as the second temperature measurement unit 44. In the present embodiment, the second temperature measurement unit 44 is disposed upstream of the pressing rollers 410 and 411 in the rotation direction of the second intermediate carrier 30. Therefore, the temperature of the pressing member 41 can be measured after having been heated and before pressing is performed.

[0061] Referring to Figs. 3C and 3D, other examples of the structure of the thinning unit 4 will be described. Figs. 3C and 3D each illustrate the structure of the thinning unit 4. The pressing member 41 shown in Figs. 3C and 3D includes two plate-shaped members 412 and 413 that face each other with the second intermediate carrier 30 therebetween. Each of the plate-shaped members 412 and 413 has a flat surface facing the second intermediate carrier 30. A mechanism (not shown) for moving the plate-shaped member 412, which comes into contact with the particle layer, in the vertical direction is provided, and the second intermediate carrier 30 and the particle layer are uniformly pressed by using the plate-shaped members 412 and 413. As illustrated in Fig. 3C, the cooling mechanism 42 cools the plate-shaped member 412, which comes into contact with the thin film, by supplying air, water, coolant, or the like to a through-member extending through the plate-shaped member 412. Alternatively, as illustrated in Fig. 3D, the cooling mechanism 42 may be omitted. In this case, the plate-shaped member 412 may be cooled by radiation by disposing the plate-shaped member 412 so as to be separated from the second intermediate carrier 30, which causes the temperature of the pressing member 41 to increase.

Operation of Three-Dimensional Forming Apparatus 1000

[0062] Next, the operation of the apparatus 1000 having the structure described above will be described. Here, assuming that generation of slice data by the main controller 2 has been already finished, a layer forming process of forming a particle layer for each layer, a thinning process of forming a thin film by heating and pressing the particle layer, and a stacking process of stacking the thin film will be described in this order. Fig. 4 is a flowchart showing the operation sequence of the apparatus 1000.

Layer Forming Process

[0063] First, the main controller 2 controls a driving source (not shown), such as a motor, so that the image carriers 100 and 110 of the first particle-image forming unit 10 and the second particle-image forming unit 11, the first intermediate carrier 14, and the second intermediate carrier 30 rotate in synchronism at the same peripheral velocity (process velocity). When the rotation velocity has stabilized, the main controller 2 causes the most upstream particle-image forming unit 10 to start forming an image (S401).

[0064] That is, the main controller 2 controls the charging device 101 to charge the entire surface of the image carrier 100 with a predetermined polarity and a predetermined electric potential. Next, the main controller 2 causes the exposure device 102 to expose the charged surface of the image carrier 100 to light in accordance with information of an image to be formed. By removing charges from an exposed portion of the surface of the image carrier 100, a potential difference is generated between the exposed portion and the unexposed portion. An image formed by the potential difference is an electrostatic latent image. The main controller 2 drives the developing device 103 to make particles of the forming material to adhere to the latent image on the image carrier 100, thereby forming a particle image of the forming material. The transfer device 104 first-transfers the particle image onto the first intermediate carrier 14.

[0065] With a predetermined time lag after the first particle-image forming unit 10 started forming an image, the main controller 2 causes the second particle-image forming unit 11 to start forming an image (S402). The second particle-image forming unit 11 forms an image in the same way as the first particle-image forming unit 10 does. The predetermined time lag of image formation is set at a value obtained by dividing the distance from the first-transfer nip of the first particle-image forming unit 10 on the upstream side to the first-transfer nip of the second particle-image forming unit 11 on the downstream side by the process velocity. Thus, two particle images formed by the first particle-image forming unit 10 and the second particle-image forming unit 11 are disposed so as to be positioned relative to each other on the first intermediate carrier 14, and a particle layer for one layer is formed from a particle image of the structural material and a particle image of the support material (S403). If there is not an overhanging portion and a support portion is not necessary, the second particle-image forming unit 11 does not form an image, and a particle layer is formed only from a particle image of the structural material.

[0066] Subsequently, the detection sensor 13 detects the particle layer on the first intermediate carrier 14, and the detection result is input to the main controller 2 (S404). The main controller 2 detects a defect of the particle layer by analyzing image information input from the detection sensor 13. For example, it is determined that the particle layer has a defect if the image of the particle layer is not a desired image, the particle layer is not found, the variation in the thickness of the particle layer is large, recovery by subsequent adjustment is difficult due to a large displacement of the position of an image of the particle layer (S405; YES).

[0067] If the particle layer does not have a defect (S405; NO), the intermediate carrier 14 transports the particle layer to the stacking unit 3. While the operation of forming a particle layer is being performed as described above, the second intermediate carrier 30 is in contact with the first intermediate carrier 14 and rotates in synchronism at the same peripheral velocity (process velocity) as the first intermediate carrier 14. At the timing at which the front end of the particle layer, which is carried by the first intermediate carrier 14, reaches the second-transfer nip, the main controller 2 applies a predetermined transfer bias to the second transfer roller 31 and transfers the particle layer to the second intermediate carrier 30 (S406).

[0068] If the main controller 2 determines that the particle layer has a defect in step S405 (S405; YES), the main controller 2 performs control so that the particle layer is not transferred to the second intermediate carrier 30. Subsequently, the belt cleaning device 12 removes the particle layer that is determined to have a defect (S415). Subsequently, a layer forming process for forming the same layer is restarted (S401).

Thinning Process

[0069] While the operation of forming a particle layer is being performed, the second intermediate carrier 30 is in contact with the first intermediate carrier 14 and rotates at the same peripheral velocity (process velocity) as the first intermediate carrier 14. The second intermediate carrier 30 continues rotating at the process velocity and transports the particle layer in the direction of the arrow in Fig. 1. When the particle layer reaches the thinning unit 4, the main controller 2 causes the heating member 40 and the pressing member 41 to heat and press the particle layer to form a thin film (S407). Referring to Fig. 5, the thinning process in step S407 will be described in detail.

[0070] First, before the particle layer reaches the thinning unit 4, each of the first and second temperature measurement units 43 and 44 performs temperature measurement (S501). The main controller 2 obtains measurement results from the first and second temperature measurement units 43 and 44 and determines whether the temperature of the pressing member 41 is lower than that of the second intermediate carrier 30 (S502). If it is determined that the temperature of the pressing member 41 is lower than that of the second intermediate carrier 30 (S502; YES), the main controller 2 causes the second intermediate carrier 30 to transport the particle layer to the thinning unit 4, and performs heating and pressing of the particle layer to form a thin film (S503).

[0071] First, in order to heat the particle layer, the main controller 2 controls the temperature of the second intermediate carrier 30 to be in a predetermined temperature range by controlling the temperature of the heating member 40 on the basis of temperature information from the first temperature measurement unit 43. The target temperature of the second intermediate carrier 30, which is heated by the heating member 40, is set in accordance with the characteristics of the structural material and the support material. For example, when the forming material is a thermoplastic resin, the target temperature is set to be higher than or equal to the highest one of the glass-transition points (Tg) of the forming materials used to form the particle layer. When the forming material is a thermoplastic elastomer, the target temperature is set to be higher than or equal to the highest one of the softening points of the forming materials used to form the particle layer. When heating the particle layer, transport of the particle layer by the second intermediate carrier 30 is stopped as necessary so that the particle layer can be sufficiently softened.

[0072] The pressing member 41 presses the particle layer, which has been heated and softened. In the case where the pressing member 41 is the pressing rollers 410 and 411, the main controller 2 controls the pressing member 41 so that the pressing rollers 410 and 411 rotate in the same direction and at the same velocity as the second intermediate carrier 30 in a contact region in which the pressing rollers 410 and 411 are in contact with the second intermediate carrier 30. In the case where the pressing member 41 is the plate-shaped members 412 and 413, when the particle layer reaches a region in which the particle layer is to be pressed by the plate-shaped members 412 and 413, the main controller 2 stops transporting the particle layer and causes the plate-shaped member 412 to press the particle layer for a predetermined time. The pressure with which and the time for which the pressing member 41 presses the particle layer are determined in accordance with the transport velocity of the second intermediate carrier 30, the time used to generate an object, and the structure of the apparatus.

[0073] If it is determined that the temperature of the pressing member 41 is higher than that of the second intermediate carrier 30 on the basis of temperature information from each of the first and second temperature measurement units 43 and 44 (S502; NO), the main controller 2 causes the cooling mechanism 42 to cool the pressing member 41 (S505). Subsequently, the main controller 2 causes the first and second temperature measurement units 43 and 44 to perform temperature measurement again (S501). If it is determined that the temperature of the pressing member 41 is lower than that of the second intermediate carrier 30 (S502; YES), the thinning process is performed (S503). Alternatively, the temperature difference between the pressing member 41 and the second intermediate carrier 30 may be controlled by increasing the heating temperature of the heating member 40. However, because the heating temperature of the heating member 40 is limited, preferably, temperature control is performed by cooling the pressing member 41.

[0074] Because the main controller 2 causes the pressing member 41 to perform pressing while controlling the temperature of the pressing member 41 to be lower than that of the second intermediate carrier 30 as described above, disorder of the thin film that may occur if a part of the thin film adheres to the pressing member 41 when the thin film is being separated from the pressing member 41 can be reduced.

Stacking Process

[0075] The thin film formed by the thinning unit 4 is transported by the second intermediate carrier 30. When the detection sensor 32 detects the position of the thin film on the second intermediate carrier 30, the main controller 2 performs position displacement correction and timing adjustment of the thin film on the basis of the detection result and causes the thin film to be transported to a predetermined stacking position (S408). At the timing at which the thin film reaches the stacking position, the main controller 2 stops the second intermediate carrier 30 and positions the thin film at the stacking position (S409). Subsequently, the main controller 2 moves the stage 34 upward to bring the surface of the stage 34 (in a case of the first layer) or the upper surface of a partially finished object on the stage 34 (in a case of the second and the following layers) into contact with the thin film carried by the second intermediate carrier 30. The stage 34 performs softening and solidifying in this state and performs stacking of the thin film (S410).

[0076] After finished stacking the thin film, the layer forming process for the next layer is started (S401). By repeatedly performing the layer forming process and the stacking process a necessary times, a partially finished object is generated on the stage 34. Lastly, an object can be obtained by removing the partially finished object from the stage 34 and removing the support material, which is water soluble, by using hot water. After removing the support material, predetermined processing, such as surface treatment or assembly, may be performed on the object to obtain a final product.

[0077] Referring to Table 1, by using an example in which an ABS resin is used as the forming material, the temperature difference between the temperature of the pressing member 41 and the temperature of the second intermediate carrier 30 in the thinning process will be described. Table 1 shows the results of observing the thin film while changing the temperature of the second intermediate carrier 30 and the temperature of the pressing member 41. In Table 1, a circle (○) represents a case where disorder of the thin film did not occur, a triangle (Δ) represents a case where occurrence of disorder of the thin film was reduced, and a cross (×) represents a case where breakage or the like of the thin film occurred.

[0078] As shown in Table 1, when a target temperature, to which the second intermediate carrier 30 was heated, was in the range of about 135°C to 180°C, disorder of a thin film was reduced if the main controller 2 performed control so that the temperature of the pressing member 41 was lower than that of the second intermediate carrier 30. In order to reduce disorder of the thin film, preferably, the main controller 2 performs control so that the temperature of the pressing member 41 is lower than the temperature of the second intermediate carrier 30 by 15 degrees or more. When the target temperature was 110°C or higher and 135°C or lower, disorder of the thin film did not occur as long as the temperature of the pressing member 41 was lower than that of the second intermediate carrier 30.

[0079] This is because, an amorphous resin, such as an ABS resin, has characteristics that the viscoelasticity changes sharply in accordance with the temperature in a temperature range that is slightly higher than its glass-transition point (110°C), but the viscoelasticity changes mildly in accordance with the temperature in a temperature range more than 135°C. That is, in the higher temperature range, the softness of the resin does not considerably differ when the temperature of the resin changes, and the difference between the adhesion of the pressing member 41 to the thin film and the adhesion of the second intermediate carrier 30 to the thin film is small.

[0080] When the temperature of the second intermediate carrier 30 was 110°C or lower, the ABS resin did not soften, and ABS resin particles were not joined together, and therefore the thin film was weak and breakage of the thin film occurred.

[0081] [Table 1]

Temperature of Pressing Member (°C)

Temperature of Second Intermediate Carrier (°C)	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185
105	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
110	Δ	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
120	O	O	O	×	×	×	×	×	×	×	×	×	×	×	×	×	×
135	O	O	O	O	Δ	Δ	×	×	×	×	×	×	×	×	×	×	×
150	O	O	O	O	O	O	O	Δ	Δ	×	×	×	×	×	×	×	×
165	O	O	O	O	O	O	O	O	O	O	Δ	Δ	×	×	×	×	×
180	O	O	O	O	O	O	O	O	O	O	O	O	O	Δ	Δ	×	×
195	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Δ	×

[0082] Fig. 8 is a graph representing the relationship between the viscoelasticity and the temperature of an ABS resin. In Fig. 8, the solid line represents the storage modulus of the ABS resin, and a dotted line represents the loss modulus of the ABS resin. The inventors of the present invention examined the relationship and found that, as illustrated in Fig. 8, the ABS resin has characteristics that a change in viscoelasticity with temperature becomes sharp as the temperature becomes higher than 110°C and a change in viscoelasticity with temperature becomes mild as the temperature becomes higher than 135°C.

[0083] In the temperature range higher than 135°C, the difference in the softness of the ABS resin for a slight difference in the temperature is small. However, when the temperature of the pressing member 41 is controlled to be lower than that of the second intermediate carrier 30 by 15 degrees or more, because the difference in the softness of the resin increases and it becomes easier to separate the thin film from the pressing member 41, disorder of the thin film can be considerably reduced. On the other hand, if the resin becomes too soft, the binding strength of the resin is reduced, and a phenomenon in which parts of the resin become separated from each other occurs. In the case of the ABS resin, this phenomenon occurred when the temperature becomes higher than 180°C, and the thin film became broken. Thus, preferably, the temperature of the pressing member 41 is controlled to be 180°C or lower.

[0084] From these results, when the ABS resin is used as the forming material, disorder of the thin film can be reduced when the temperature T1 of the second intermediate carrier and the temperature T2 of the pressing member satisfy expressions (1) to (3). When expression (4) is satisfied, disorder of the thin film can be further reduced.

110°C < T1 (1)

T2 is less than or equal to 180°C (2)

T2 < T1 (3)

T2 is less than or equal to T1 - 15°C (4)

Advantages of Present Embodiment

[0085] With the apparatus 1000 described above, because the main controller 2 controls the temperature of the pressing member 41 to be lower than that of the second intermediate carrier 30, disorder of the thin film, which may occur due to adhesion of a part of the thin film to the pressing member 41 when the thin film is being separated from the pressing member 41, can be reduced. This is because, if the temperature of the pressing member 41 is lower than that of the second intermediate carrier 30, the adhesion between the second intermediate carrier 30 and the thin film is stronger than the adhesion between the pressing member 41 and the thin film.

Second Embodiment

[0086] Referring to Fig. 6, a three-dimensional forming apparatus according to a second embodiment will be described. Fig. 6 is a schematic view illustrating the structure of a thinning unit 4 according to the second embodiment. In the first embodiment, pressing rollers or plate-shaped members are used as the pressing member 41 for thinning a particle layer. In the second embodiment, a pressing belt is used. In the thinning unit 4 of the first embodiment, the pressing member 41 is disposed downstream of the heating member 40 in the transport direction. In the second embodiment, the heating member 40 and the pressing member 41 are disposed so as to face each other with the second intermediate carrier 30 therebetween, and simultaneously perform heating and pressing. The heating member 40 also functions as the pressing member 41. In other respects, the structure of the second embodiment is the same as that of the first embodiment. Hereinafter, descriptions of portions of the second embodiment the same as those of the first embodiment will be omitted, and only the structures specific to the second embodiment will be described.

[0087] The thinning unit 4 according to the present embodiment includes the heating member 40, the pressing member 41, the cooling mechanism 42, the first temperature measurement unit 43, and the second temperature measurement unit 44. The pressing member 41 includes a belt 61, rollers 62 and 63, and the heating member 40. The heating member 40 also functions as the pressing member 41. The belt 61 is a pressing belt that is looped over the two rollers 62 and 63 and is disposed on a side of the second intermediate carrier 30 on which a particle layer is supported. The main controller 2 controls the rotation directions and the rotation velocities of the plurality of rollers 62 and 63 so that the belt 61 and the second intermediate carrier 30 moves in the same direction and at the same velocity in a contact region in which the belt 61 and the second intermediate carrier 30 are in contact with each other. The width of the belt 61 and the width of the heating member 40 are each grater than that of the particle layer.

[0088] With the structure of the present embodiment, disorder of the thin film can be reduced if the temperature of the belt 61 is lower than that of the second intermediate carrier 30 at a position at which the thin film is separated from the belt 61, that is, at the downstream end portion of the belt 61 in the transport direction. Therefore, preferably, the first temperature measurement unit 43 measures the temperature of the second intermediate carrier 30 at a position downstream of the pressing member 41 in the transport direction, and the second temperature measurement unit 44 measures the temperature of a portion of the belt 61 on the downstream side in the transport direction. The cooling mechanism 42 cools the roller 62, which is disposed on the downstream side in the transport direction. The cooling mechanism 42 may be provided for each of the rollers 62 and 63. The roller 63, which is disposed on the upstream side in the transport direction, may function as a heating member.

[0089] Also with the present embodiment described above, because the main controller 2 controls the temperature of the pressing member 41 to be lower than that of the second intermediate carrier 30, occurrence of disorder of the layer, which may occur when the pressed layer is being separated from the pressing member, can be reduced. In the present embodiment, it is sufficient that, when the thin film is being separated from the belt 61, the temperature of the pressing member 41 is controlled to be lower than that of the second intermediate carrier 30.

[0090] With the structure of the present embodiment, because the pressing belt is used as the pressing member 41, heating and pressing can be performed for a sufficiently long time without stopping transportation by the second intermediate carrier 30. Therefore, the time required for generating an object can be reduced. Moreover, because pressing can be performed over a large area, a thin film having a more uniform surface can be formed.

Third Embodiment

[0091] A three-dimensional forming apparatus according to a third embodiment will be described. Figs. 7A and 7B illustrate examples of the structure of a thinning unit 4 according to the third embodiment. In the thinning unit 4 of the first embodiment, the pressing member 41 is disposed downstream of the heating member 40 in the transport direction. In the third embodiment, the heating member 40 and the pressing member 41 are disposed so as to face each other with the second intermediate carrier 30 therebetween, and heating and pressing are simultaneously performed. The heating member 40 also functions as the pressing member 41. In other respects, the structure of the third embodiment is the same as that of the first embodiment. Hereinafter, descriptions of portions of the third embodiment the same as those of the first embodiment will be omitted, and only the structures specific to the third embodiment will be described.

[0092] The thinning unit 4 according to the present embodiment includes the heating member 40, the pressing member 41, the cooling mechanism 42, the first temperature measurement unit 43, and the second temperature measurement unit 44. The heating member 40 is a heater having a flat surface facing the second intermediate carrier 30. The pressing member 41 includes the heating member 40 and a plate-shaped member 71. The plate-shaped member 71 has a mechanism for moving in a direction perpendicular to the transport direction and presses a particle layer by pressing the plate-shaped member 71 against the second intermediate carrier 30. The areas of flat surfaces of the heating member 40 and the plate-shaped member 71 facing the second intermediate carrier 30 are each greater than the area of the particle layer.

[0093] As illustrated in Fig. 7A, the cooling mechanism 42 cools the plate-shaped member 71 by supplying air, water, a coolant, or the like to a through-member extending through the plate-shaped member 71. Alternatively, as illustrated in Fig. 7B, the cooling mechanism 42 may be omitted. The plate-shaped member 71 may cooled by disposing the plate-shaped member 71 so as to be separated from the second intermediate carrier 30, which causes the temperature of the pressing member 41 to increase, so that the plate-shaped member 71 can be cooled by heat radiation.

[0094] The plate-shaped member 71 may also function as the heating member, and the particle layer may be heated also from above. In this case, it is sufficient that, when separating the thin film from the plate-shaped member 71, the temperature of the plate-shaped member 71 is lower than that of the second intermediate carrier 30.

[0095] Also with the present embodiment described above, because the main controller 2 controls the temperature of the plate-shaped member 71, which is the pressing member 41, to be lower than that the second intermediate carrier 30, occurrence of disorder of the pressed layer, which may occur when the layer is being separated from the pressing member, can be reduced.

[0096] By using the plate-shaped member as the pressing member 41, pressing can be performed over a larger area, and therefore a thin film having a more uniform surface can be formed.

[0097] Heretofore, embodiments of the present invention have been described. However, the present invention is not limited to the embodiments described above and can be modified or changed within the sprit and scope of the present invention. The embodiments described above can be used in combination as appropriate.

[0098] For example, in step S502 of the embodiment described above, whether the temperature of the pressing member 41 is lower than that of the second intermediate carrier 30 is determined. In addition, whether the difference between the temperature of the pressing member 41 and the temperature of the second intermediate carrier 30 is greater than a predetermined value may be determined. By measuring the temperature of the pressing member 41, the main controller 2 may perform control so that the temperature of the pressing member 41 does not become higher than a predetermined temperature. Here, the predetermined temperature may be, for example, the glass transition temperature of the forming material, the heating temperature of the heating member 40, the target temperature of the second intermediate carrier 30, or the like.

[0099] In the embodiment described above, the apparatus 1000 includes the first and second intermediate carriers 14 and 30. Alternatively, the apparatus may include only one intermediate carrier. In this case, a particle layer, which is formed by transferring particle images formed on the plurality of particle-image forming units 10 and 11 to an intermediate carrier, is not transferred to another intermediate carrier, and is transported to the thinning unit 4 and the stacking unit 3. Further alternatively, the intermediate carrier may include another intermediate carrier between the first intermediate carrier 14 and the second intermediate carrier 30.

[0100] In the embodiment described above, a layer is formed on the transport member by using an electrophotographic process. However, a layer may be formed by using a process different from the electrophotographic process. For example, an inkjet process may be used, and the present invention can be applied to the method described in WO2014/092205. For another example, a fused deposition modeling process, in which a resin (forming material) is melted by heat and is stacked little by little, may be used.

[0101] While the present invention has been described with reference to embodiments, it is to be understood that the invention is not limited to the disclosed embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

[0102] This application claims the benefit of Japanese Patent Application No. 2014-242521 filed November 28, 2014 and No. 2015-218804 filed November 6, 2015, which are hereby incorporated by reference herein in their entirety.

Reference Signs List

[0103] 1 layer forming unit
2 controller
3 stacking unit
4 thinning unit
10, 11 particle-image forming unit
30 transport member (second intermediate carrier)
40 heating member
41 pressing member
100, 110 image carrier

Claims

[Claim 1] A forming apparatus for forming a three-dimensional object by using a forming material, comprising:
a layer forming unit that forms a layer by using the forming material;
a transport member that transports the layer formed by the layer forming unit;
a heating unit that heats the layer supported by the transport member;
a pressing unit that presses the layer when the layer is heated by the heating unit or after the layer has been heated by the heating unit; and
a stacking unit that stacks the layer pressed by the pressing unit at a stacking position,
wherein the forming apparatus is configured so that a temperature of the pressing unit in contact with the layer is lower than a temperature of the transport member.

[Claim 2] The forming apparatus according to Claim 1, wherein the forming material includes a plurality of materials, and the heating unit heats the layer so that the temperature of the layer becomes higher than or equal to a highest one of glass-transition points of the plurality of materials.

[Claim 3] The forming apparatus according to Claim 1 or 2, wherein the forming apparatus is configured so that a difference between the temperature of the transport member and a temperature of a surface of the pressing unit in contact with the layer is 15 degrees or more.

[Claim 4] The forming apparatus according to Claim 1 or 2, wherein the forming apparatus is configured so that a temperature of a surface of the pressing unit in contact with the layer is not a predetermined temperature or higher.

[Claim 5] The forming apparatus according to any one of Claims 1 to 4, further comprising a mechanism that cools the pressing unit by using air or water.

[Claim 6] The forming apparatus according to any one of Claims 1 to 4, further comprising a mechanism that separates the pressing unit from the transport member and that cools the pressing unit by heat radiation.

[Claim 7] The forming apparatus according to any one of Claims 1 to 6, wherein the heating unit heats the layer from a side opposite to a surface of the transport member supporting the layer in a state in which the heating unit is separated from the transport member.

[Claim 8] The forming apparatus according to any one of Claims 1 to 6, wherein the heating unit heats the layer from a side facing a surface of the transport member on which the layer is disposed in a state in which the heating unit is separated from the transport member.

[Claim 9] The forming apparatus according to any one of Claims 1 to 6, wherein the heating unit heats the layer from a side opposite to a surface of the transport member on which the layer is disposed in a state in which the heating unit is in contact with the transport member.

[Claim 10] The forming apparatus according to Claim 9, wherein the heating unit is integrated with the pressing unit.

[Claim 11] The forming apparatus according to any one of Claims 1 to 10, wherein the pressing unit is disposed downstream of the heating unit in a direction in which the transport member transports the layer.

[Claim 12] The forming apparatus according to any one of Claims 1 to 11, further comprising:

a first temperature measurement unit that measures a temperature of a surface of the transport member; and

a second temperature measurement unit that measures a temperature of a surface of the pressing unit in contact with the layer,

wherein the forming apparatus is configured so that the temperature of the pressing unit in contact with the layer is lower than the temperature of the transport member on the basis of a measurement result of the first temperature measurement unit and a measurement result of the second temperature measurement unit.

[Claim 13] The forming apparatus according to Claim 12, wherein the pressing unit includes two pressing rollers facing each other with the transport member therebetween, and

wherein the second temperature measurement unit measures a temperature of one of the two pressing rollers that is disposed on a side of the transport member on which a surface of the transport member supporting the layer is located.

[Claim 14] The forming apparatus according to Claim 12, wherein the pressing unit includes two rollers and a belt looped over the two rollers, the two rollers being disposed on a side of the transport member supporting the layer, and

wherein the second temperature measurement unit measures a temperature of a portion of the belt that is located on a downstream side in a transport direction of the transport member.

[Claim 15] The forming apparatus according to any one of Claims 1 to 14,

wherein the transport member is a first transport member,
wherein the layer forming unit includes a plurality of particle-image forming units,
wherein the forming apparatus further comprises a second transport member that receives particle images formed by the plurality of particle-image forming units and transferred thereto and thereby forms the layer, and
wherein the first transport member transports the layer transferred from the second transport member.

[Claim 16] The forming apparatus according to any one of Claims 1 to 15, wherein the layer forming unit includes a particle-image forming unit that forms a particle image by developing an electrostatic latent image formed on an image carrier by using the forming material, and the layer forming unit forms a particle layer by transferring the particle image to the transport member.

[Claim 17] A method of making a three-dimensional object by using a forming material, comprising:
a layer forming step of forming a layer by using the forming material;
a transport step of transporting the layer formed in the layer forming step by using a transport member;
a heating step of heating the layer;
a pressing step of pressing the layer by using a pressing unit when the layer is heated in the heating step or after the layer has been heated in the heating step; and
a stacking step of stacking the layer pressed in the pressing step,
wherein the method is such that a temperature of a surface of the pressing unit in contact with the layer is lower than a temperature of the transport member.

[Claim 18] A three-dimensional object generated by using the method according to Claim 17.

AMENDED CLAIMS
received by the International Bureau on 31 March 2016 (31.03.2016)

[Claim 1] (Amended) A forming apparatus for forming a three-dimensional object by using a forming material, comprising:

a layer forming unit that forms a layer by using the forming material;

a transport member that transports the layer formed by the layer forming unit;

a heating unit that heats the layer supported by the transport member;

a pressing unit that presses the layer when the layer is heated by the heating unit or after the layer has been heated by the heating unit;

a stacking unit that stacks the layer pressed by the pressing unit at a stacking position;

a first temperature measurement unit that measures a temperature of a surface of the transport member; and

a second temperature measurement unit that measures a temperature of a surface of the pressing unit in contact with the layer,

wherein the temperature of the pressing unit in contact with the layer is controlled to be lower than the temperature of the transport member on the basis of a measurement result of the first temperature measurement unit and a measurement result of the second temperature measurement unit.

[Claim 2] The forming apparatus according to Claim 1,

wherein the forming material includes a plurality of materials, and the heating unit heats the layer so that the temperature of the layer becomes higher than or equal to a highest one of glass-transition points of the plurality of materials.

[Claim 3] (Amended) The forming apparatus according to Claim 1 or 2,

wherein a difference between the temperature of the transport member and a temperature of a surface of the pressing unit in contact with the layer is controlled to be 15 degrees or more.

[Claim 4] (Amended) The forming apparatus according to Claim 1 or 2,

wherein a temperature of a surface of the pressing unit in contact with the layer is controlled not to be a predetermined temperature or higher.

[Claim 5] The forming apparatus according to any one of Claims 1 to 4, further comprising a mechanism that cools the pressing unit by using air or water.

[Claim 6] The forming apparatus according to any one of Claims 1 to 4, further comprising a mechanism that separates the pressing unit from the transport member and that cools the pressing unit by heat radiation.

[Claim 7] The forming apparatus according to any one of Claims 1 to 6,

wherein the heating unit heats the layer from a side opposite to a surface of the transport member supporting the layer in a state in which the heating unit is separated from the transport member.

[Claim 8] The forming apparatus according to any one of Claims 1 to 6,

wherein the heating unit heats the layer from a side facing a surface of the transport member on which the layer is disposed in a state in which the heating unit is separated from the transport member.

[Claim 9] The forming apparatus according to any one of Claims 1 to 6,

wherein the heating unit heats the layer from a side opposite to a surface of the transport member on which the layer is disposed in a state in which the heating unit is in contact with the transport member.

[Claim 10] The forming apparatus according to Claim 9, wherein the heating unit is integrated with the pressing unit.

[Claim 11] The forming apparatus according to any one of Claims 1 to 10,

Wherein the pressing unit is disposed downstream of the heating unit in a direction in which the transport member transports the layer.

[Claim 12] (Deleted)

[Claim 13] (Amended) The forming apparatus according to Claim 1,

wherein the pressing unit includes two pressing rollers facing each other with the transport member therebetween, and

wherein the second temperature measurement unit measures a temperature of one of the two pressing rollers that is disposed on a side of the transport member on which a surface of the transport member supporting the layer is located.

[Claim 14] (Amended) The forming apparatus according to Claim 1,

wherein the pressing unit includes two rollers and a belt looped over the two rollers, the two rollers being disposed on a side of the transport member supporting the layer, and

wherein the second temperature measurement unit measures a temperature of a portion of the belt that is located on a downstream side in a transport direction of the transport member.

[Claim 15] (Amended) The forming apparatus according to any one of Claims 1 to 11, 13 and 14,

wherein the transport member is a first transport member,

wherein the layer forming unit includes a plurality of particle-image forming units, wherein the forming apparatus further comprises a second transport member that receives particle images formed by the plurality of particle-image forming units and transferred thereto and thereby forms the layer, and

wherein the first transport member transports the layer transferred from the second transport member.

[Claim 16] (Amended) The forming apparatus according to any one of Claims 1 to 11 and 13 to 15,

wherein the layer forming unit includes a particle-image forming unit that forms a particle image by developing an electrostatic latent image formed on an image carrier by using the forming material, and

the layer forming unit forms a particle layer by transferring the particle image to the transport member.

[Claim 17] (Amended) A method of making a three-dimensional object by using a forming material, comprising:

a layer forming step of forming a layer by using the forming material;

a transport step of transporting the layer formed in the layer forming step by using a transport member;

a heating step of heating the layer supported by the transport member;

a measuring step of measuring a temperature of a surface of the transport member and a temperature of a surface of the pressing unit in contact with the layer,

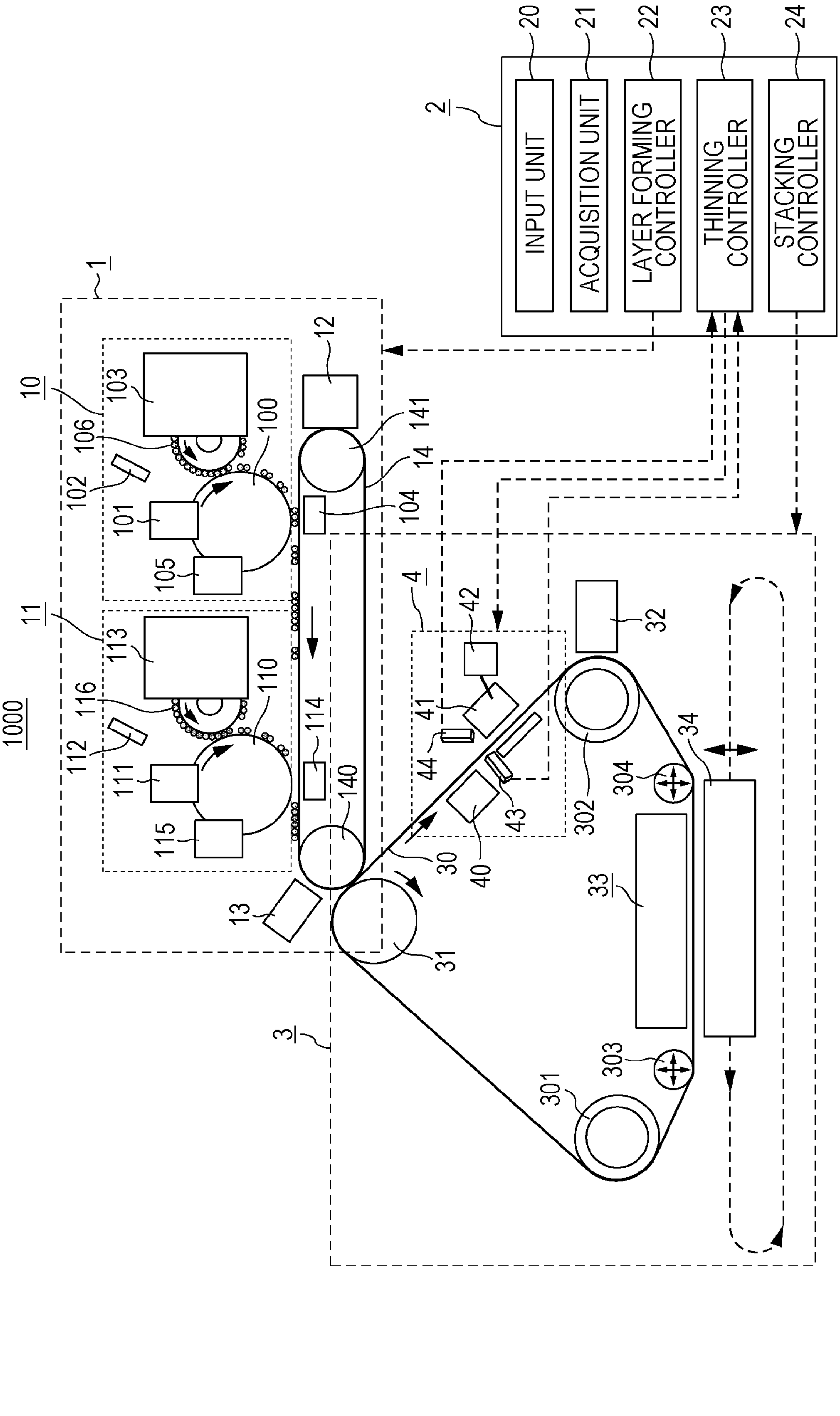
a pressing step of pressing the layer by using a pressing unit when the layer is heated in the heating step or after the layer has been heated in the heating step; and

a stacking step of stacking the layer pressed in the pressing step,

wherein a temperature of a surface of the pressing unit in contact with the layer is controlled to be lower than a temperature of the transport member based on a measurement result provided by the measuring step.

[Claim 18] A three-dimensional object generated by using the method according to Claim 17.

[Fig. 1]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THINNING CONTROLLER
STACKING CONTROLLER
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13
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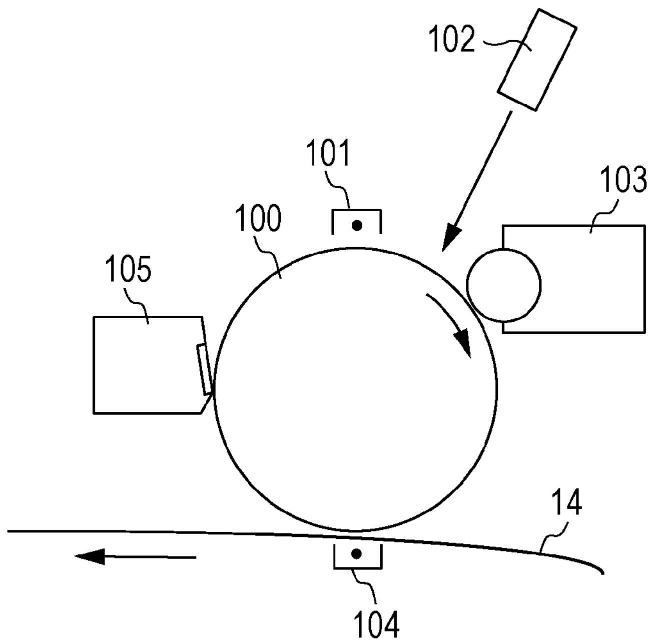
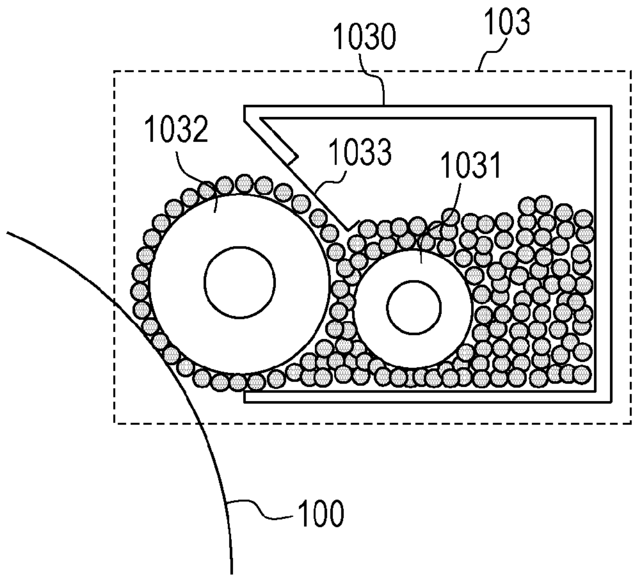
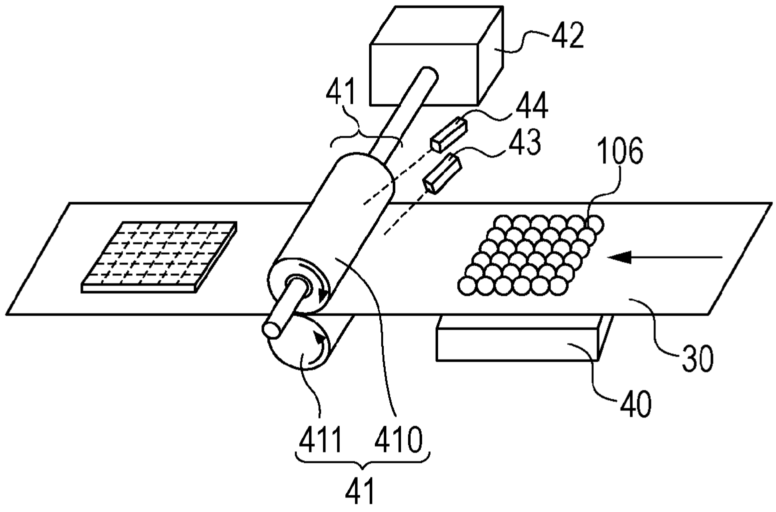
[Fig. 2A]



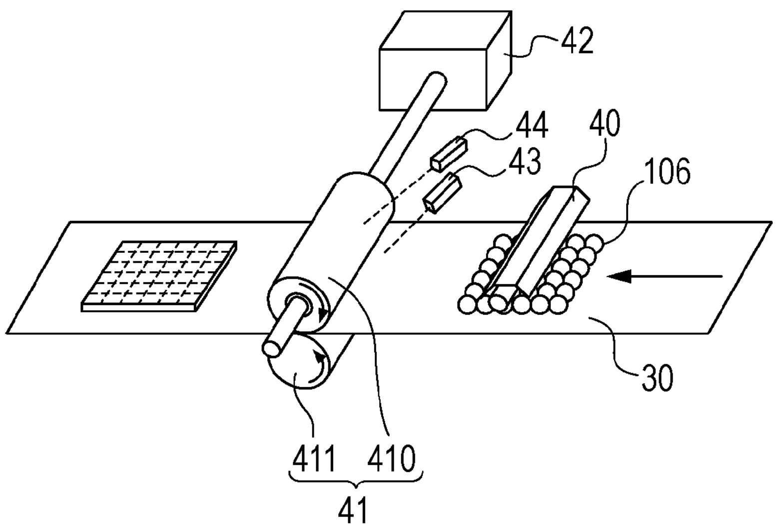
[Fig. 2B]



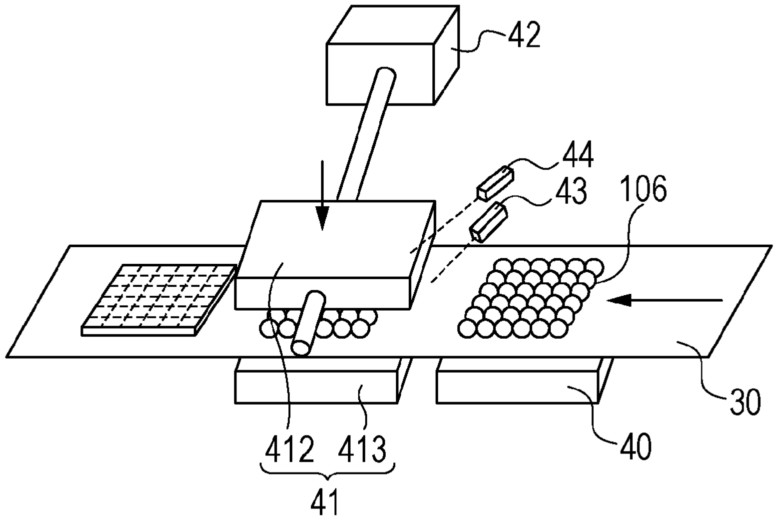
[Fig. 3A]



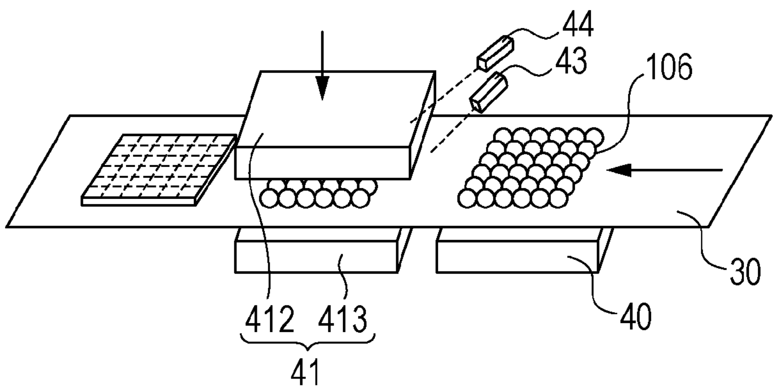
[Fig. 3B]



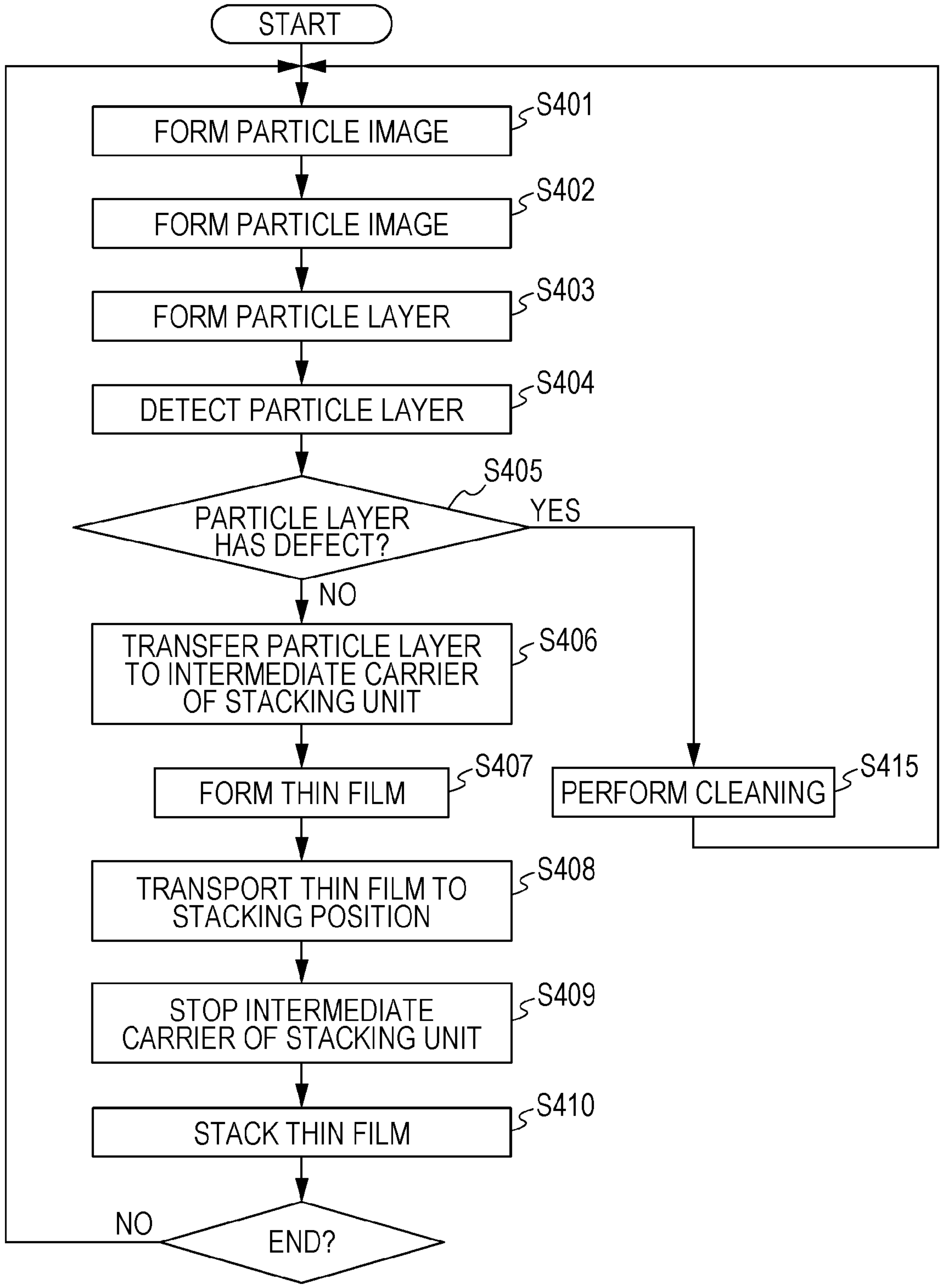
[Fig. 3C]



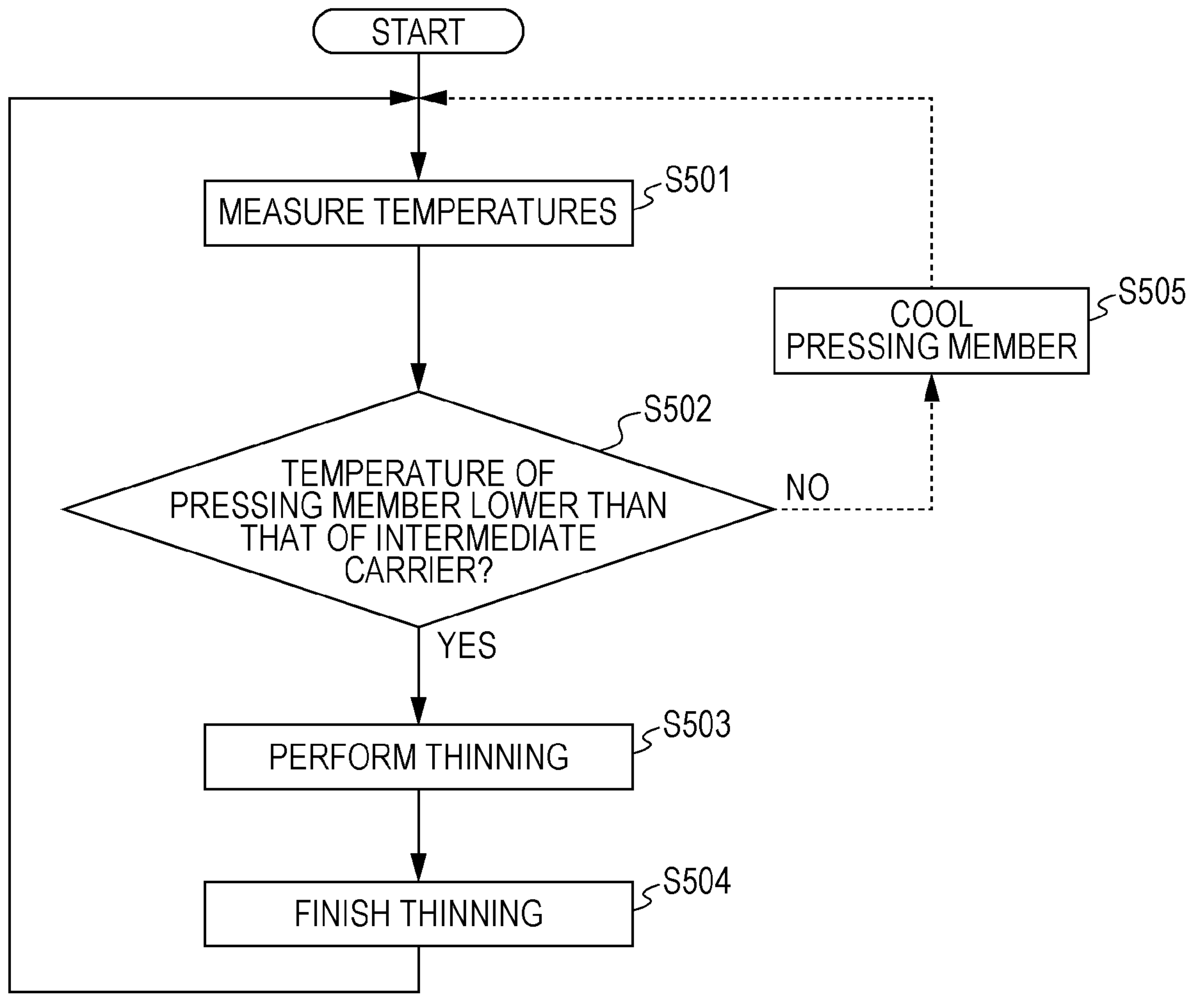
[Fig. 3D]



[Fig. 4]


START
FORM PARTICLE IMAGE
S401
FORM PARTICLE IMAGE
S402
FORM PARTICLE LAYER
S403
DETECT PARTICLE LAYER
S404
PARTICLE LAYER HAS DEFECT?
S405
YES
NO
TRANSFER PARTICLE LAYER TO INTERMEDIATE CARRIER OF STACKING UNIT
S406
FORM THIN FILM
S407
PERFORM CLEANING
S415
TRANSPORT THIN FILM TO STACKING POSITION
S408
STOP INTERMEDIATE CARRIER OF STACKING UNIT
S409
STACK THIN FILM
S410
NO
END?

[Fig. 5]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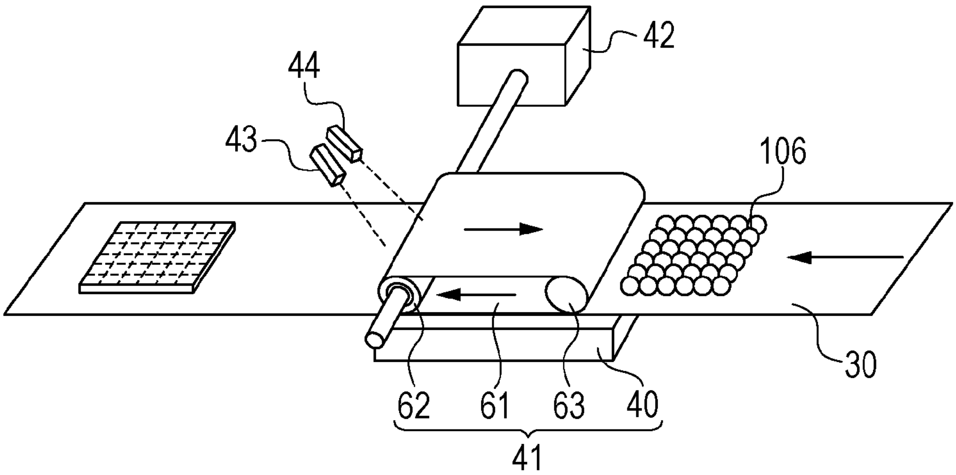
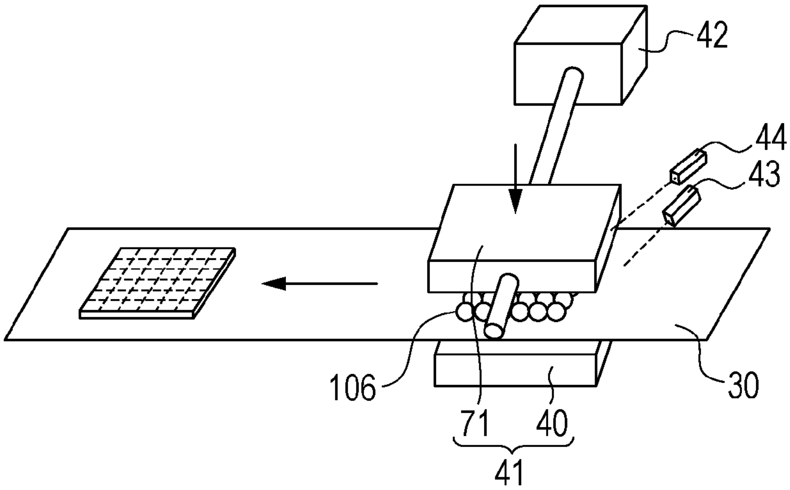
MEASURE TEMPERATURES
S501
TEMPERATURE OF PRESSING MEMBER LOWER THAN THAT OF INTERMEDIATE CARRIER?
S502
NO
YES
COOL PRESSING MEMBER
S505
PERFORM THINNING
S503
FINISH THINNING
S504

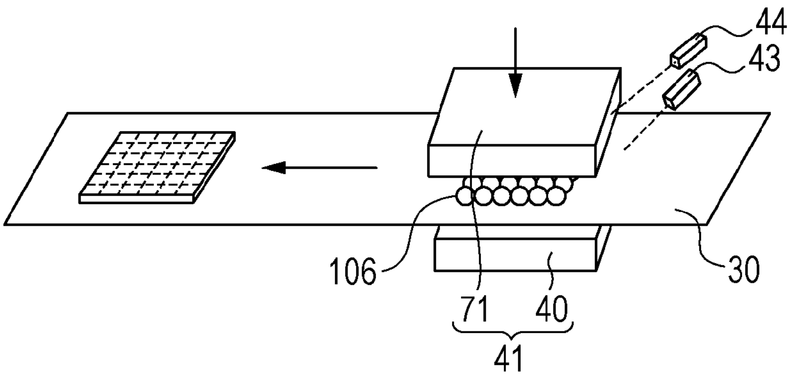
[Fig. 6]



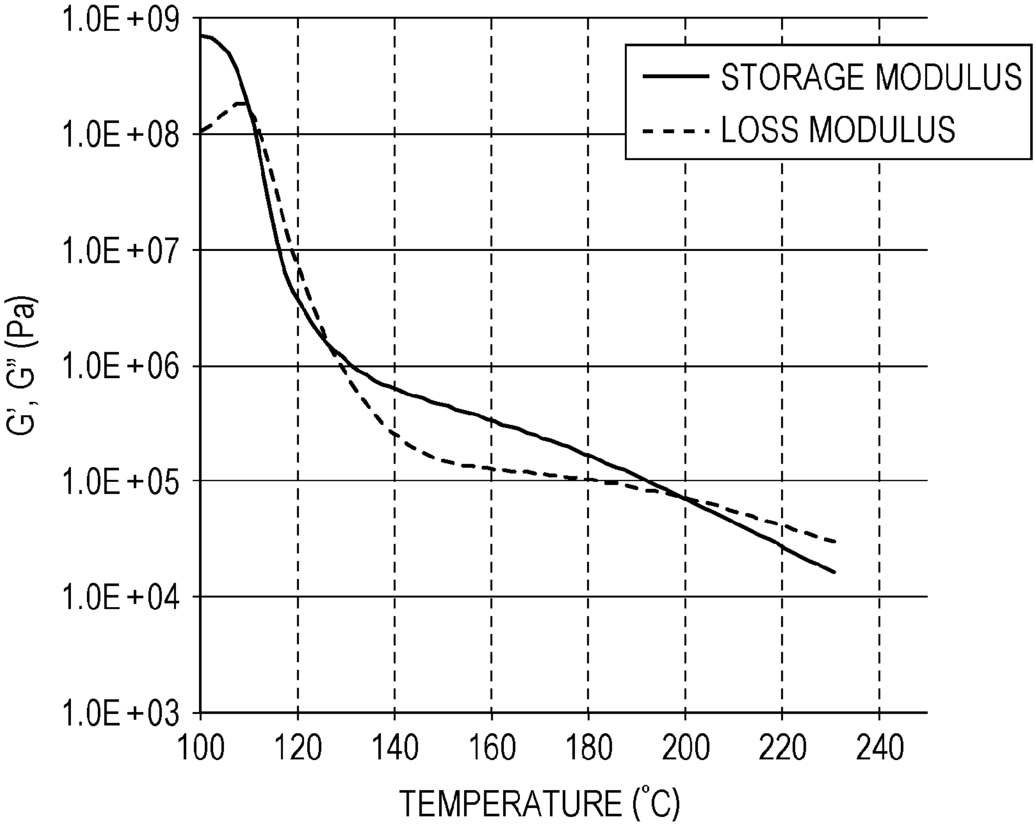
[Fig. 7A]



[Fig. 7B]



[Fig. 8]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1.0E+06
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G', G" (Pa)
100
120
140
160
180
200
220
240
TEMPERATURE (°C)
STORAGE MODULUS
LOSS MODULUS

INTERNATIONAL SEARCH REPORT

International application No
PCT/JP2015/005767

A. CLASSIFICATION OF SUBJECT MATTER
INV. 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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	WO 95/26871 A1 (GRENDA EDWARD P [US]) 12 October 1995 (1995-10-12) figures page 10, line 15 - page 22, line 14	1-11, 15-18 12-14
X A	US 2013/075013 A1 (CHILLSCYZN STEVEN A [US] ET AL) 28 March 2013 (2013-03-28) paragraph [0053] - paragraph [0062] page 1 figure 1 claims 1,9,15	18 1-17

☐ Further documents are listed in the continuation of Box C.

☒ 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

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"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
2 February 2016	11/02/2016

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	Whelan, Natalie

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/JP2015/005767

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		WO 9526871 A1	12-10-1995
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