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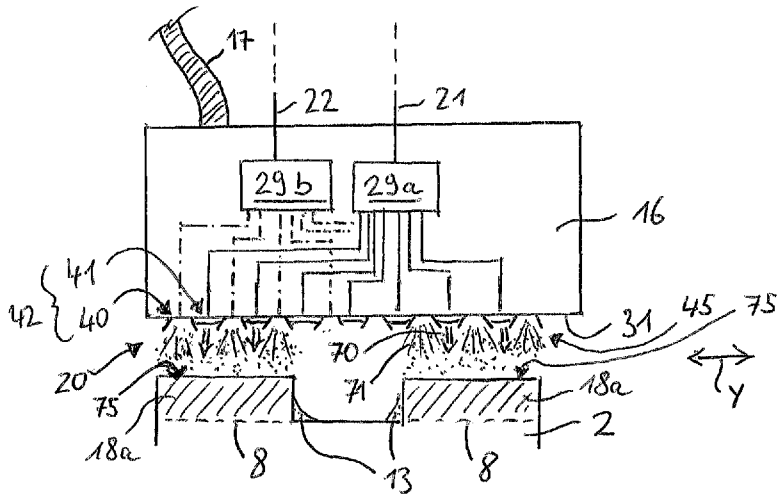
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(54) Title: BUILDING MATERIAL AND RADIATION SOURCE MODULE AND ADDITIVE MANUFACTURING DEVICE COMPRISING THE MODULE

Fig. 2



(57) Abstract: A building material and radiation source module (16) for an additive manufacturing device (1) for manufacturing a three-dimensional object (2) by a solidification of a building material (18) within a building area (8) comprises: at least two units (42), each unit comprising a building material outlet (40) for generating a building material stream (71) directed to a target area (75) within the building area (8) and at least one radiation source (41) for providing a radiation (70) to interact with the building material stream (71), wherein each building material outlet (40) is individually switchable and each radiation source (41) is individually switchable and wherein the module (16) is configured to be continuously moved over at least a part of the building area (8) and to selectively apply the building material streams (71) and the radiation (70) in regions of an object (2) to be built, by selectively switching the building material outlets (40) and the radiation sources (41).

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Building material and radiation source module and additive manufacturing device comprising the module

The present invention relates to a building material and radiation source module for an additive manufacturing device for manufacturing a three-dimensional object by a solidification of a building material within a building area, and to such an additive manufacturing device comprising the module. The invention further relates to a method for manufacturing a three-dimensional object by a solidification of a building material within a building area, a control unit for an additive manufacturing device for the manufacture of a three-dimensional object by a solidification of a building material, and to a computer program comprising a sequence of instructions that enables a control unit to perform the steps of the method when the computer program is loaded and executed in the control unit.

Several methods are known in which a building material source and a radiation source act concurrently in an additive manufacturing device for manufacturing a three-dimensional object.

According to one such method known as laser cladding, a laser spot moves relative to a substrate to generate a melt pool while a powdered cladding material is injected into the melt pool to create a fully dense bead of the cladding metal that is fusion bonded to the substrate. Such a method is described, for example, in Murphy, M.L., Steen, W.M. and Lee, C.: "*The Rapid Manufacture of Metallic Components by Laser Surface Cladding*", in: Conf. Proceedings of Laser Assisted Net Shape Engineering, p. 803-814 (1994). As noted therein, almost any metallic powder can be used as a cladding material and the exact composition of the clad bead can be altered at any time during the process. Also, the geometry of the deposited clad bead can be controlled by adjusting the laser parameters, powder feed parameters and the traverse rate of the spot.

Further, as described in König, W., Celiker, T., and Song, Y.-A.: "*Process Development for Direct Manufacturing of Metallic Parts*", in: Conf. Proceedings of Laser Assisted Net Shape Engineering, p. 785-792 (1994), by moving a laser beam relative to the substrate a cladded track can be generated. For 3-dimensional structures, the single tracks are laid side by side or on top of each other. However, a thickness of the individual layers thus created depends on the powder feed rate and on the processing speed to be controlled carefully. Also, in case of complex geometries, a maintenance of a constant layer thickness may have to be effected by, e.g., elaborate five-axis handling systems.

US 5,993,554 A describes a direct material deposition apparatus. Multiple laser beams and a deposition head having multiple powder nozzles are used in order to increase the deposition rate. The conical deposition head has an array of powder nozzles, wherein streams of powder interact with focused laser beams directed through the cone to form line depositions on a deposition substrate. Four laser beams form a linear array, and each of the focused laser beams has independent on-off control. Eight filler powder nozzles are arranged in pairs at the deposition head to yield intersecting powder material streams near the deposition plane. Two outline powder nozzles interact with each one pair of filler powder nozzles to provide powder used to form external or internal deposited features. Translation of a deposition surface relative to the laser beams to create a 3-dimensional part is permitted by computer control.

EP 2 502 729 A1 describes an additive manufacturing system including a laser source directed at a deposition point and a pair of powder delivery systems, which each comprise a valve system for controlling a flow of powder feed at the common deposition point.

In each of the above described applications, a free form structure is formed based on methods in a manner of laser cladding, in which a substrate or a worktable, which receives the substrate, is moved relative to the components of the device such as a laser source and powder nozzles which are fixed with respect to a XY plane, which in turn necessitates accurate control of XY-movements and directions of powder feed application, respectively. This may increase either expenditure in machinery and control components and/or a time duration to form a free form structure in each case.

It is an object of the invention to provide a module for an additive manufacturing device for manufacturing a three-dimensional object by a solidification of a building material within a building area, which addresses at least some of the above-mentioned drawbacks. It is also an object to provide a corresponding additive manufacturing device and a method for manufacturing a three-dimensional object by a solidification of a building material within a building area using the module.

The object is solved by a module for an additive manufacturing device according to claim 1, by an additive manufacturing device including at least one of such modules according to claim 10, by a method according to claim 13 for manufacturing a three-dimensional object by a solidification of a building material within a building area using the module, by a control unit for an additive manufacturing device according to claim 14 and by a computer program according to claim 15 . Further developments or advantageous aspects are described in the dependent claims. In the course of this, the manufacturing apparatus and the control unit may be further specified by the method features described herein below and provided in the claims, and vice versa. Features of different advantageous further developments and embodiments can further be combined among each other.

An inventive building material and radiation source module for an additive manufacturing device for manufacturing a three-dimensional object by a solidification of a building material within a building area comprises:

at least two units, each unit comprising a building material outlet for generating a building material stream directed to a target area within the building area and at least one radiation source for providing a radiation to interact with the building material stream,

wherein each building material outlet is individually switchable and each radiation source is individually switchable and

wherein the module is configured to be continuously moved over at least a part of the building area and to selectively apply the building material streams and the radiation in regions of an object to be built, by selectively switching the building material outlets and the radiation sources.

Herein, the module substantially describes a scanning movement over the target area of the building area and the at least one building material outlet as well as the at least one radiation source may each be individually switched on or off, where appropriate, to deposit a structure in the building area. There are provided at least two units at the module each having a building material outlet as well as radiation source. Accordingly, during the movement, for example one line of deposition structures may be formed due to switching on the one unit, while a position or line of an underlying surface scanned by the respective other unit may be left freely exposed, because, e.g., neither the radiation source is switched on, nor the building material outlet is switched on, or both. Since at least two of the units are provided in this manner, selective deposition becomes efficient, and more surface area can be scanned by the module within a given time.

By providing at least both units in the same module, i.e., the units move together, the motion control system in an additive manufacturing apparatus becomes simple, because fewer parts allow perform more efficient tasks. Alignment accuracy and position management is improved in view of a continuous movement of the module in (for example) just one direction.

Moreover, because each building material outlet is individually switchable, a considerable amount of building material can be saved as compared with a case wherein those building material outlets cannot be individually switched off. In such a case, building material dispensed from all of the outlets of the module would simply be left unsolidified where a corresponding radiation source would be switched off, in order to manufacture a respective cross-sectional layer of the object. In contrast, according to embodiments of the invention, by switching off also the individual building material outlet in a selective manner at the specific deposition point in the building area, the corresponding excess building material can be saved. Also, the weight of a build container during manufacturing is considerably reduced when there is deposited no or just a small amount of excess building material inside the container besides the object to be built.

The at least one radiation source may be a laser source, preferably a diode laser or a fiber laser etc., that is provided in a respective unit. However, the radiation source may also be an optical fiber coupled to a respective remote laser source. Still further, it is possible that the radiation sources are provided as one or more mirrors or deflectors provided in the module which are irradiated with respective beams from a laser source, etc. The invention is not limited to the specific type of radiation source. For example, the radiation sources as described in the embodiments below may also be provided as high density energy beam emitters or particle beam emitters. In any case, the beams are provided (depending on the characteristics of the building material) with capability to heat, melt and/or sinter the building material and/or a material which at the deposition surface to allow generating a deposition structure which is more or less integral with material residing below. The materials need not be the same.

The at least one building material outlet may generally be connected (e.g., via flexible or rigid conduits) with a building material reservoir of a device for distributing building material. Such reservoir may be on-board the module or may also be provided externally, e.g., at other components of an additive manufacturing device which houses the module. Sub-tanks (such as on-board building material reservoirs) may optionally be provided on a module which serve as a buffer storage, and which may be connected between an external building material reservoir (provided at the additive manufacturing apparatus) and the building material outlets.

The building material outlets may be configured to dispense a beam of powdery material (e.g, powder or powder mixtures with fibres) or a liquid material (e.g., droplets or droplet mixtures with fibres). The building material outlets may for example comprise each one or more powder or fluid nozzles. The building materials may be metallic or ceramic or organic polymers or mixtures thereof, etc. The invention is not limited to specific materials dispensed.

It is also encompassed that different building material reservoirs are provided for each building material outlet. I.e., each building material outlet may be provided with its distinct building material reservoir. Each building material reservoir may store the same or different building materials which can be selectively provided to each of the building material outlets using a

system composed of conduits including valves selectively controlled by a control unit. Mixing of different building materials may also be effected thereby. The building material distribution system may include a device which drives a transport of the building material (e.g., powder or liquid) from the building material reservoir to the building material outlet through the selectively controlled valves.

The process to be performed by the interaction between each of the radiation sources and the corresponding building material outlets may include a method similar to that used in laser cladding.

In a preferable embodiment, the module is configured to be continuously moved over an entire two-dimensional extension of the building area. In that instance, an advantage arises in that the three-dimensional object may be entirely formed by the selective switching of the building material outlets and radiation sources, respectively. I.e., application of the module becomes most efficient.

In another preferable embodiment, the at least two units are arranged in the module so as to form at least one row comprising two, three, four, five, six or a larger multitude of adjacently arranged units, the at least one row extending in an Y-direction within the building area, wherein the module is configured to be moved over the building area in a direction slanted or transverse with respect to the Y-direction or substantially perpendicular (e.g., an X-direction) to the Y-direction. According to this embodiment, the units are arranged to extend along one direction, and the module may move in another direction slanted, transverse or perpendicular to the direction defined by the row. As a consequence, the continuous movement of module leads to a scan of a substantially rectangular area within the building area. This may advantageously lead to an efficient coverage of the entire building area by just one scan movement (although multiple movements are not ruled out, wherein the module is displaced in the Y-direction between subsequent movements), during which the building material outlets and radiation sources are selectively controlled. The number of units per row may be selected according to the needs with regard to resolution.

In a more refined aspect of such embodiment, the at least one row includes two, three, four, or a multitude of rows which are (preferably pairwise) staggered with respect to each other in the Y-direction. Such an arrangement allows to increase the number of units per unit length in the Y-direction even when adjacent units within one row are positioned close to each other. As the two or more rows each extend in the Y-direction side by side in the slanted, transverse or perpendicular direction (e.g., an X-direction), the (pairwise or mutual) staggering allows that all the units involved in these rows – when projected along the scan- or X-direction onto a line parallel to the rows – cover a distinct section on such line. A suitable staggering for example achieves an equidistant distribution of the points on the line in Y-direction projected from all of the respective units. As a consequence, the overall resolution is considerably improved and very fine-detailed structures can be generated.

In another preferable embodiment, an overall length of the at least one row in the Y-direction is not less than a maximum extent of the building area in the Y-direction, such that by moving the module in a direction slanted or transverse or substantially perpendicular to the Y-direction, the entire field of the building area can be covered by the target areas of the building material streams exiting the building material outlets. In such an arrangement, the building area may be entirely scanned by the module by means of just one movement, which increases the efficiency. Also, the movement velocity may be then chosen smaller than in a case where multiple reciprocating movements become necessary, in order to get the same result. A reduced velocity in turn may improve the control of the deposited structures because in many cases, the powder or fluid beam supply to a deposition point on an object or substrate surface is inclined with respect to a building plane and a moving underground imposes an effect on the deposited material.

In a more refined aspect of such embodiment, the two, three, four, or a multitude of rows are (preferably pairwise) staggered with respect to each other in the Y-direction to such an extent that by moving the module in a direction slanted, transverse or substantially perpendicular to the Y-direction, the entire two-dimensional extension of the building area can be covered with the building material streams exiting the building material outlets. Herein, the advantages recited above are even further improved.

Additionally or alternatively, the target areas covered by the individual building material streams within the building area maybe sized such that by moving the module in a direction slanted, transverse or substantially perpendicular to the Y-direction, the entire two-dimensional extension of the building area can be covered with the building material streams exiting the building material outlets. Herein, the similar advantageous effects as noted above are achieved with regard to a simple structure, reduced time, and increased resolution.

In another preferable embodiment, the capability of each building material outlet of being individually switched includes: i) an individual ON/OFF-switching selectively permitting or interrupting the building material stream, and/or ii) an individual gradual, continuous or stepwise control of at least one parameter of the building material stream, such as a flow rate, a stream shape and/or a type of building material. While ON/OFF switching offers a simple structure, gradual, continuous or stepwise control allows keep track of amounts of powder or fluid exceeding quantities that can be treated with melting and/or sintering. Hence, amounts of powder or liquid material can be saved, and the process chamber may kept in more clean state. Also, amounts of powder material may be chosen in dependence of radiation power such that a size, in particular for example the thickness, of the deposited structure can be controlled to some extent.

In another preferable embodiment, the capability of each radiation source of being individually switched includes i) an individual ON/OFF-switching of the radiation source and/or ii) an individual gradual, continuous or stepwise control of at least one parameter of the radiation, such as an intensity, a wavelength, a radiation beam shape, a radiation beam direction or a radiation beam convergence/focusing. Herein, similar effects as noted in the previous paragraph can be achieved. A particular advantageous embodiment arises when gradual, continuous or stepwise control each of the individual building material outlets and the individual radiation sources is achieved. In that case, the control of the building material outlets is made in dependence of control of radiation sources, respectively, for each of the units.

In another preferable embodiment, in a cross section of at least one of the units, the cross section being taken parallel to the building area, the radiation source is arranged within, preferably approximately centrally within, the building material outlet. In such an arrangement, a symmetry of the powder or liquid supply with respect to the radiation, laser or high energy particle beam is most efficient. Due to such symmetry, for example, the movement of the module with the units actively depositing material may occur in the X-direction as well as in the opposite direction (i.e., in a reciprocating movement).

An inventive additive manufacturing device for manufacturing a three-dimensional object by a solidification of a building material within a building area comprises at least one module as described above. As an example, the additive manufacturing device may be configured to manufacture a three-dimensional object by a *layer-wise* solidification of the building material. In this case, the module is configured to be continuously moved over at least a part of the building area and to selectively apply the building material streams and the radiation in regions of a respective *layer* corresponding to a cross section of the object to be built, by selectively switching the building material outlets and the radiation sources.

In a preferable embodiment, the additive manufacturing device further comprises a device for removing an excess building material provided by the building material outlets towards the target areas and left unsolidified, wherein the device for removing an excess building material is configured to remove the excess building material during a step of manufacturing a layer of the object and/or between steps of manufacturing layers of the object. Although at least in some of the above described embodiments, the invention allows to save building material and thus reduces the costs of manufacturing and also contributes to the cleanness of a process chamber, the arrangement of this embodiment further improves the cleanness and precision of manufacturing a three-dimensional object. Also, the building material dispensed but left unsolidified is removed and assembled in, e.g., a container, may optionally be reused. Using the device for removing an excess building material, the excess building material can be removed in situ just when dispensing of building material and solidification has occurred. Undesirable accumulation of excess building material is thereby advantageously avoided or at least reduced.

Preferably the device for removing an excess building material comprises a container for collecting an excess building material, the container being arranged adjacent the building area and adjacent the object being built and having a collecting opening which faces the object being built. In one embodiment, the container is located directly below the building area, such that the excess building material is removed at least by gravity. Nevertheless, a blower and/or a vacuum device or system may support the removal process according to more refined embodiments.

In another preferable embodiment, the additive manufacturing device further comprises a device for distributing building material, the device for distributing building material being in separable communication with the building material outlets, wherein the device for distributing building material comprises two, three, or a multitude of independent building material reservoirs each provided with an independent valve for independently providing a building material from any (one) of the building material reservoirs to one or more of the building material outlets. Such a device for distributing building material permits to selectively control each of the valves in order to dispense building material from each of the building material outlets individually.

An inventive method for manufacturing a three-dimensional object by a solidification of a building material within a building area uses a module according to one of the above described embodiments, wherein the object is manufactured by continuously moving the module over at least a part of the building area and selectively applying the building material streams and the radiation in those regions which correspond to a cross section of the object to be built by selectively switching the building material outlets and the radiation sources. Herein the same or similar effects may be achieved as noted above.

An inventive control unit for an additive manufacturing device for the manufacture of a three-dimensional object by a solidification of a building material is configured to control the additive manufacturing device such as to carry out a method as defined in the preceding para-

graph. For example, the control unit effects and adjusts the movement of the module and selectively switches the building material outlets (e.g., activates respective valves) and the radiation sources in a controlled manner.

An inventive computer program comprises a sequence of instructions that enables a control unit to carry out a method as defined above when the computer program is loaded and executed in the control unit. Such a program permits to achieve the aspects and advantages as explained above.

It is noted that in the description of specific embodiments below, even if for example in Fig. 1 a specific device is described as an example for an additive manufacturing device, aspects of the invention are not restricted to that embodiment. In case the additive manufacturing method is not based on the principles of laser sintering, laser melting or laser cladding, the radiation sources may be embodied as energy introduction devices different from lasers or laser diodes. In general, instead of a laser any device, by means of which energy may be selectively introduced into a layer of the building material using electromagnetic radiation or particle radiation can be used. For example, instead of a laser, an electron beam emitting device may be used. In the case of a stereolithographic method the solidification device is an ultraviolet light source. In view of the above, the further explanations and embodiments detailed below are not meant to be limited to laser sintering, laser melting or laser cladding, even if only corresponding methods are mentioned.

It is further noted that various materials may be used as the building material in the additive layer-wise manufacturing method presented herein, preferably powders or pastes, in particular metal powders, but also plastic powders, ceramic powders or sand. Also the use of filled or mixed powders is possible. Liquid photo polymers are used particularly in stereolithography. Additionally, liquid metals may also be used as the building material. Liquids are dispensed herein as drops or droplets from the building material outlets. Also, the powdery material, e.g, powder or powder mixtures may include fibres. Similarly, the liquid material (e.g., liquid metal or polymer droplets or droplet mixtures) may include fibres.

It is further noted that also two or more of the modules may be combined on a common movable platform or device, or even on different, separately movable platforms or devices in the same additive manufacturing apparatus.

In the following the invention will be described by making reference to the drawings, wherein:

Fig. 1 is a schematic illustration of an exemplary additive manufacturing apparatus according to an embodiment of the invention,

Fig. 2 shows details of a module of the device shown in Fig. 1,

Fig. 3 shows from below an arrangement of units comprising building material outlets and radiation sources in mutually staggered rows at a module shown in Fig. 1,

Fig. 4 shows a top view onto a module according to an embodiment of the invention guided by rails over a building area of the device of Fig. 1,

Fig. 5 shows a device for distributing building material to the building material outlets in the context of the invention.

For a better understanding of the invention, in the following an example of an additive manufacturing device according to the invention will be described with reference to Fig. 1. By means of an inventive additive manufacturing device not only one object but also several objects may be manufactured at the same time, even in cases in which only one object is mentioned.

For building an object 2 the additive manufacturing device 1 comprises a process chamber or building chamber 3 having a chamber wall 4.

A building container 5, which is open to the top and which has a container wall 6 is arranged in the process chamber 3. The opening at the top of the building container 5 defines a work plane 7. The part of the work plane 7 that lies inside of the opening and that can be used for building the object 2 is designated as a construction field or a building area 8.

A support 10 that can be moved in a vertical direction V is arranged in the building container 5. A bottom plate 11 is attached to the support 10, which bottom plate 11 seals the container 5 at the bottom and thus forms the container bottom. The bottom plate 11 may be a plate formed separately from the support 10 and fixed to the support 10. Alternatively, the bottom plate 11 may be formed integrally with the support 10. Depending on the powder that is used and on the process that is used, it is possible that a further building platform 12 is mounted on the bottom plate 11 as building support, on which the object 2 is built. Though such a building platform 12 is exemplarily shown in Fig. 1, the object 2 may also be built on the bottom plate 11 itself, which then serves as building support.

Moreover, in Fig. 1 the object 2 that is to be formed in the container 5 on the building platform 12 is shown below the work plane 7 in an intermediary state with several solidified layers (not shown in detail). Also, excess building material 13 which had not been solidified is shown as being assembled in small amounts on bottom plate, 11, building platform 12 or on horizontal surfaces of object 2.

The additive manufacturing device 1 in Fig. 1 contains a supply container 14 for storing a building material 18 (in this example a powder that can be solidified by means of electromagnetic radiation). The supply container 14 is connected to a movable module 16, which includes an arrangement 20 of building material outlets 40 and radiation sources 41 as will be explained in detail below with reference to Fig. 2, via a flexible tube 17 such as to supply building material 18 to the module 16. Optionally, a radiative heating such as an infrared radiator 19 may be arranged in the process chamber 3, which radiative heating serves for a heating of the building material 18 while being supplied. The supply container 14 and its function may be controlled by a control unit 29 to be described below via a connection line 25.

The additive manufacturing device 1 shown in Fig. 1 contains the module 16, which is movable along a horizontal direction X such as to scan the construction field or building area 8. Thereby, the module 16 is driven by a motor 15 such as a linear or step motor or the like, which will be explained in more detail with respect to Fig. 4 below.

Furthermore, the additive manufacturing device 1 comprises a control unit 29 by means of which the individual parts of the device 1 are controlled in a coordinated manner for carrying out the building process. Alternatively, parts of the control unit 29 or the complete control device may be arranged outside of the additive manufacturing device 1. The control unit may comprise a CPU, the operation of which is controlled by a computer program (software). Such computer program can be stored on a storage medium inside of the control unit 29. Alternatively, it may be stored on a storage medium remote from the device 1, from which storage medium it is then loaded, e.g. via a network, into the device 1, particularly into the control unit 29.

When the device 1 according to this embodiment is in operation, the support 10 is lowered by a thickness corresponding to one layer formed at the object 2 by the control unit 29, and the module 16 is moved by the control unit 29 in a coordinated manner via motor 15 such that it scans over the construction field or building area 8 along the X-direction. Thereby, the building material outlets 40 and radiation sources 41 provided at a bottom surface 31 of the module 16 are also controlled by the control unit 29 such as to selectively dispense a building material 18 through the building material outlets in a building material stream directed to a target area 75 and to solidify the building material being deposited in the construction field or building area 8 by radiation using the radiation sources 41, respectively, wherein the radiation interacts with the particle stream and the powder/droplets deposited in the target area 75. With each scan over the construction field or building area 8, a new layer is formed upon object 2, and subsequent to each scan, the support 10 is repeatedly lowered as explained above.

In an additive manufacturing method the multiple radiation sources may for example comprise one or more gas or solid state lasers or any other kind of lasers such as laser diodes, in particular VCSELs (vertical cavity surface emitting lasers) or VECSELs (vertical external cavity

surface emitting lasers) or it may comprise a linear arrangement of such lasers. Irrespective of the fact, whether for example by a linear arrangement of lasers or by other measures the radiation incident on the building material is line-shaped or covers a certain area, throughout this specification the term "beam" or “radiation” is used for describing a ray bundle hitting the building material. It is further noted that the specific setup of an additive manufacturing device shown in Fig. 1 is only by way of example and of course could be changed in many ways.

It may be noted that while the present embodiment describes an exemplary additive layer-wise manufacturing device and method with corresponding module according to the invention, other embodiments involve deposition of solidification of building material 18 in which no layers are formed. Rather, deposition of solidification therein occurs at appropriate locations of an object 2 to be built, wherein these locations may not represent a single layer. Instead, by adjusting the amount of building material dispensed or the intensity of radiation emitted from a radiation source between respective units of the module (which will be explained below), more complex three dimensional structures having varying thickness and/or depth with respect to the work plane 7 may be formed even within just one scan or movement of the module 16 over the building area 8, and even more in multiple subsequent scans.

When carrying out the above-described additive layer-wise manufacturing method according to the embodiment shown in Fig. 1, the control unit 29 executes instructions according to a set of control commands. The instructions selectively specify the actuation of some of the building material outlets to dispense a powdery material or liquid droplets etc. in a building material stream directed to a target area 75 in the building area 8. Also, switching-on of for example corresponding ones of the radiation sources is effected to solidify the dispensed building material with respect to regions specified for a respective layer. Such regions correspond to a cross-section of an object to be manufactured in the respective layer. Thus, the control command set contains information on the positions in a layer that have to be solidified.

The control command set is based on a computer-based model of one or more objects to be manufactured, preferably a CAD volume model. It usually also contains the layer information, i.e. the way in which one or more objects to be manufactured are split up into layers that correspond to the building material layers during the layer-wise additive manufacturing. Here, those control data that are related to a single layer are designated as layer data set.

Furthermore, information specific to the manufacturing process is included in the command control set, e.g. the position and orientation of the objects in the container 5 or a beam diameter of the laser beam emitted from radiation sources 41 and/or a building material stream diameter of the powdery or liquid droplet material dispensed from the building material outlets 40. The control command set may in particular also specify the thickness of each building material to be applied from each building material outlet during the manufacturing process. In particular, the control command set may comprise all data necessary for a control of each of the radiation sources such as the energy density of the radiation emitted by the respective radiation source and the scan velocity of the module.

In summary, the control command set may be regarded as the entirety of all control data that are provided for the control of the manufacturing process in the additive layer-wise manufacturing device 1 of the present embodiment, but also of other embodiments encompassed by the invention.

With reference to Fig. 2, an embodiment of a module 16 as shown in the exemplary device 1 of Fig. 1 is depicted schematically in a front view (along the X-direction). The dimensions are not drawn to scale. The module 16 has a bottom surface 31 comprising the arrangement 20 of building material outlets 40 and radiation sources 41 as described above. The module 16 is arranged such that the bottom surface 31 faces the construction field or building area 8 in a distance suitable to deposit the powdery material or liquid droplets locally and to irradiate or solidify the deposited material efficiently, so that a reasonable resolution is achieved and few building material is lost (left unsolidified). A distance may amount, e.g., to 10-30 mm, i.e. at least 10mm and/or 30mm at most, but other arrangements or distances are encompassed as well and the invention is not limited to that specific range.

As can be seen in Fig. 2, the building material outlets 40 and the radiation sources 41 are arranged in an alternate or pairwise manner. Accordingly, each pair of building material outlets 40 and radiation sources 41 conjunctly forms a "dispense-and-solidification" unit 42. Thereby, parts 40 and 41 of the same unit 42 are positioned such that the radiation or beam emitted from the radiation source 41 covers the powdery or droplet beam or at least the location of the deposition point of that beam.

The control unit 29 includes in the embodiment shown respective controllers 29a and 29b which are provided on-board the module 16. Communication lines 21 and 22 allow transferring instructions to the module 16. Radiation source controller 29a is configured to receive instructions via communication line 21 pertaining to a selective switching-on or switching-off of the radiation sources 41 arranged at the module 16. Building material outlet controller 29b is configured to receive instructions via communication line 22 pertaining to a selective switching-on or switching-off of the building material outlets 41 arranged at the module 16. It is noted that in other embodiments, the controller 29a, 29b may be formed as one controller. Also, controllers 29a, 29b can be formed remote/external from the module 16, and/or may be formed as a part of the CPU of control unit 29. As shown in Fig. 2, each radiation source 41 and each building material outlet 40 of each unit 42 is individually and distinctly connected to one of respective controllers 29a, 29b, to allow for selective switching-on or switching-off.

For example, as schematically shown in Fig. 2, several building material outlets 40 and radiation sources 41 arranged in a mid-portion of the module 16 as sees in the Y-direction are switched-off, while other building material outlets 40 and radiation sources 41 are activated (see arrows in case of radiation sources and dots in case of building material outlets) to form a new layer of solidified building material 18a on top of object 2 at selected locations. Note that since the building material outlets 40 in the mid-portion in this example are switched-off, excess building material 13 which is not solidified because the respective radiation sources are also switched-off is considerably reduced and thus, costs are saved and advantageously, an excessive weight of the filled powder bed in the building container 5 may be avoided according to these embodiments.

Turning back to Fig. 1, it is shown therein a device 80 for removing an excess building material 13 provided by the building material outlets 40 towards the target areas 75 and left unsolidified. The device 80 for removing an excess building material 13 is configured to remove the excess building material 13 either during a step of manufacturing a layer of the object 2 or between steps of manufacturing layers of the object 2, or during and between these steps. Preferably the device 80 for removing an excess building material 13 comprises a container 82 for collecting an excess building material 13. The collected excess building material may be recycled and optionally fed back into supply container 14, if appropriate. The container 82 is for example arranged adjacent the building area 8 and adjacent the object 2 being built and has a collecting opening 83 which faces the object 2 being built. The excess building material 13 may be collected by suction. The process of collection is controlled by control unit 29 via connection line 27.

With respect to Fig. 3, a bottom view onto the bottom surface 31 of the module 16 is depicted, which includes an arrangement 20 of building material outlets 40 and a radiation sources 41. The units 42 each comprising a building material outlet 40 and a radiation source 41 are arranged in rows 45, 45', 45", 45"'. Each of the rows 45, 45', 45", 45"' comprises a multitude of units 42 extending along a direction X transverse to the direction of movement of the module across the building area 8 (see, e.g., Fig. 4).

In the schematic drawing of Fig. 3, each row includes only 9 units, but the person skilled in the art will readily recognize, that in order to provide the full width of the building area 8 with units 20 with sufficient resolution during solidification, more (or perhaps even less) units may be formed at module 16 according to the needs. Also, there are shown four rows 45, 45', 45", 45"' of units 42 in Fig. 3, but there may be conceived more or less than 4 rows to increase the resolution or to decrease a width of module 16. Alternatively, more than one module 16 such as that shown in Fig. 3 may be arranged on a common platform or device which traverses the building area 8 in a scanning movement.

Within each unit 42, the radiation source 41 is arranged in a center positon while the associated building material outlet 40 symmetrically surrounds radiation source 41. As a consequence, due to such symmetry, the building material 18 being dispensed is irradiated and solidified most efficiently by the associated radiation source 41 and further, the efficiency of solidification is not dependent from the direction of movement of the module 16 with respect to the deposition surface on object 2.

As can be seen in Fig. 3, the rows 45, 45', 45", 45"' of arrangement 20 are pairwise staggered with respect to each other in the Y-direction. More specifically, adjacent rows are offset with respect to each other by about ¼ of a length of unit 42 in the Y-direction. As a consequence, when the radiation sources are projected along the X-direction onto a common line 51 parallel to the Y-direction and transverse or perpendicular to the moving direction of module 16, it can be seen that the radiation sources 41 equidistantly cross over the building area 8, which reflects an increased resolution (resolution width 52 in Fig. 3) during solidification despite the large widths of units 42 due to the comparatively large size of the building material outlets 40.

With reference to Fig. 4, a top view of the module 16 traversing the building area 8 along the X-direction is shown. The module 16 is in this embodiment guided on rails 55a, 55b and driven by, e.g., a step or linear motor 15, for example via a belt or the threaded rod, etc. The arrangement 20 of rows 45, 45', 45", 45"' including units 42 is arranged on a bottom surface 31 of module 16 and faces the building area 8. A length of arrangement 20 in the length direction of module 16 is such that the entire width of the building area 8 in the Y-direction is covered by the arrangement 20. Hence, by just one scan movement of the module 16 in X-direction, the entire building are 8 may be scanned by units 42 and may thereby be provided with building material and solidifying irradiation at selected positions, herein for example on top of object 2. Thereby, building material 18 used-up in the module 16 is replenished from supply container 14 via flexible tube 17.

By means of the control unit 29 and motor 15 controlled via communication line 23, the module 16 is configured to be continuously moved over at least a part of the building area 8 such as to selectively apply the building material streams 71 and the radiation 70 in regions of an

object 2 to be built, by selectively switching the building material outlets 40 and the radiation sources 41 in accordance with the position of module in X-direction and the cross sectional positions of the object to be built in the XY-plane, or building area 8. Instead of a continuous movement, a gradual or even stepwise movement of the module 16 is possible as well.

Also, during the scan movement of the module 16 across the building area 8, the building material stream 71 produced at each of the building material outlets 40 may be individually varied depending on the module position as well as between outlets 40. For example, pure ON/OFF-switching selectively permits or interrupts the building material stream 71. Additionally, the building material stream 71 may be individually varied with respect to, e.g., flow rate, stream shape and/or a type of building material 18 used or mixed.

Similarly, during the scan movement of the module 16 across the building area 8, also the radiation 70 emitted from each of the radiation sources 41 may be individually varied depending on the module position as well as between radiation sources 41. For example, pure ON/OFF-switching selectively permits or interrupts the radiation. Additionally, the radiation 70 may be individually varied with respect to, e.g., an intensity, a wavelength, a radiation beam shape, a radiation beam direction or a radiation beam convergence/focusing, etc.

With reference to Fig. 5, a schematic illustration of a device 60 for distributing building material 18 to the building material outlets 40 is explained. The device 60 in this embodiment for example has three different building material reservoirs 60a, 60b and 60c which are provided in the module 16, and which may store different kinds of building materials 18, respectively. Each of the building material reservoirs 60a, 60b and 60c may optionally be connected to supply container 14 via flexible tube 17 to allow for replenishment with building material 18, respectively. The device 60 further includes a controller 29c (connected to control unit 29, not shown in Fig. 5) which is configured to actuate and open a respective valve 61a, 61b, 61c provided at each of the building material reservoirs 60a, 60b and 60c, in order to select a desired building material or to provide a desired mixture. For example, building material reservoir 60a

may include a metal or ceramic powder and building material reservoirs 60b and 60c may include different types of fibers to be mixed with the powder of reservoir 60a. Alternatively, different metal or ceramic powders etc. may be provided in reservoirs 60a-60c.

Transport of the building material 18 (or its mixture) to the building material outlets may be effected by a pressurized carrier gas (not shown) in case of powdery materials. Each building material outlet 40 is provided as a powder nozzle including each a valve, which is actuated by the building material outlet controller 29b in accordance with the instructions obtained via communication line 22 from the control unit 29.

More specifically, as noted above, depending on the position of the module 16 (or the building material outlet 40 or the radiation source 41 on the module 16) with respect to the building plane, which position is also controlled by control unit 29 via communication line 24 (see Fig. 1), the controller 29b obtains instructions from control unit 29 to switch-on or to switch-off the building material outlet 40 by opening or closing its valve in accordance with corresponding cross sectional data of the object 2 to be manufactured with regard to the instant layer. When the respective valves are opened at selected locations, the building material 18 enters the powder nozzles, is further pressurized and is dispensed on the deposition point or area at object 2.

Similarly, the radiation sources 41 are centered in units 42 within the powder nozzles of the building material outlets 40. As shown in Fig. 5, when the building material is dispensed from selected units 42, the radiation source controller 29a simultaneously operate the respective radiation sources 41 associated with these selected units to irradiate the dispensed and deposited building material. Thereby, the controller 29a may also control the radiation sources 41 to vary the irradiated power dependent on the position of the target area in order to achieve a desired surface finish or three-dimensional surface profile at the object 2 being manufactured, etc. The building material outlet controller 29b may similarly vary the discharge rate dependent on the position of the target area within the areas of the cross section which are to be solidified.

Various modifications may be made with regard to the above embodiments without departing from the scope defined in the appended claims. For example, in the above embodiments, the supply container 14 is external from the module 16. However, the supply container may similarly be provided on the module 16 (on-board) thereby itself forming the building material reservoir. Similarly, there may be no building material reservoir on-board, and the building material 18 is directly supplied to the building material outlets from an external supply container 14 via tubes 17. Also, there may be just one, or two, or more than 3 building material reservoirs.

Additionally, in the above embodiments, one unit 42 is shown to comprise one building material outlet and one radiation source. One unit is shown to be individually and selectively controllable by control unit 29. However, it is also possible, that one unit 42 comprises more than one building material outlet and/or more than one radiation source. For example, one building material outlet may be surrounded by a laser diode array instead of one laser diode being surrounded by one building material outlet, etc.

Claims:

1. A building material and radiation source module (16) for an additive manufacturing device (1) for manufacturing a three-dimensional object (2) by a solidification of a building material (18) within a building area (8), the module (16) comprising:

at least two units (42), each unit comprising a building material outlet (40) for generating a building material stream (71) directed to a target area (75) within the building area (8) and at least one radiation source (41) for providing a radiation (70) to interact with the building material stream (71),

wherein each building material outlet (40) is individually switchable and each radiation source (41) is individually switchable and

wherein the module (16) is configured to be continuously moved over at least a part of the building area (8) and to selectively apply the building material streams (71) and the radiation (70) in regions of an object (2) to be built, by selectively switching the building material outlets (40) and the radiation sources (41).

2. The module (16) according to claim 1,

wherein the module (16) is configured to be continuously moved over a total two-dimensional extension of the building area (8).

3. The module (16) according to one of the preceding claims,

wherein the at least two units (42) are arranged in the module so as to form at least one row (45, 45', 45", 45"') of two, three, four, five, six or a multitude of adjacently arranged units (42), the at least one row extending in a Y-direction within the building area (8),

and wherein the module (16) is configured to be moved over the building area (8) in a direction slanted with respect to the Y-direction or substantially perpendicular to the Y-direction.

4. The module (16) according to claim 3,

wherein the at least one row (45, 45', 45", 45"') includes two, three, four, or a multitude of rows which are staggered, preferably pairwise staggered, with respect to each other in the Y-direction.

5. The module according to claim 3 or 4,

wherein an overall extension of the at least one row (45, 45', 45", 45"') in the Y-direction is not less than a maximum extension of the building area (8) in the Y-direction,

such that by moving the module (16) in a direction slanted with respect to the Y-direction or substantially perpendicular to the Y-direction, the entire two-dimensional extension of the building area (8) can be covered by the target areas (75) of the building material streams (71) exiting the building material outlets (40).

6. The module (16) according to claim 3 to 5,

wherein the two, three, four, or a multitude of rows (45, 45', 45", 45"') are staggered, preferably pairwise staggered, with respect to each other in the Y-direction to such an extent

and/or wherein the target areas (75) covered by the individual building material streams (71) within the building area (8) are sized such

that by moving the module (16) in a direction slanted with respect to the Y-direction or substantially perpendicular to the Y-direction, the entire two-dimensional extension of the building area (8) can be covered with the building material streams (71) exiting the building material outlets (40).

7. The module (16) according to one of the preceding claims,

wherein the capability of each building material outlet (40) of being individually switched includes

i) an individual ON/OFF-switching selectively permitting or interrupting the building material stream (71) and/or

ii) an individual gradual, continuous or stepwise control of at least one parameter of the building material stream (71), such as a flow rate, a stream shape and/or a type of building material (40).

8. The module (16) according to one of the preceding claims,

wherein the capability of each radiation source (41) of being individually switched includes

i) an individual ON/OFF-switching of the radiation source (41) and/or

ii) an individual gradual, continuous or stepwise control of at least one parameter of the radiation (70), such as an intensity, a wavelength, a radiation beam shape, a radiation beam direction or a radiation beam convergence/focusing.

9. The module (16) according to one of the preceding claims,

wherein in a cross section of at least one of the units (42), the cross section being taken parallel to the building area (8), the radiation source (41) is arranged within, preferably approximately centrally within, the building material outlet (41).

10. An additive manufacturing device (1) for manufacturing a three-dimensional object (2) by a solidification of a building material (18) within a building area (8),

the device (1) comprising at least one module (16) according to one of the preceding claims.

11. The additive manufacturing device (1) according to claim 10,

the additive manufacturing device (1) further comprising a device (80) for removing an excess building material (13) provided by the building material outlets (40) towards the target areas (75) and left unsolidified,

wherein the device (80) for removing an excess building material (13) is configured to remove the excess building material (13) during a step of manufacturing a layer of the object (2) and/or between steps of manufacturing layers of the object (2),

wherein preferably the device (80) for removing an excess building material (13) comprises a container (82) for collecting an excess building material (13), the container (82) being arranged adjacent the building area (8) and adjacent the object (2) being built and having a collecting opening (83) which faces the object (2) being built.

12. The additive manufacturing device (1) according to one of claims 10 or 11,

further comprising a device for distributing building material, the device for distributing building material being in separable communication with the building material outlets,

wherein the device for distributing building material (18) comprises two, three, or a multitude of independent building material reservoirs (14, 60a-c) each provided with an independent valve for independently providing a building material from any of the building material reservoirs to one or more of the building material outlets.

13. A method for manufacturing a three-dimensional object by a solidification of a building material within a building area (8) using a module according to one of claims 1 to 9,

wherein the object (2) is manufactured by continuously moving the module (16) over at least a part of the building area (8) and selectively applying the building material streams (71) and the radiation (70) in those regions which correspond to a cross section of the object (2) to be built

by selectively switching the building material outlets (40) and the radiation sources (41).

14. A control unit (29) for an additive manufacturing device (1) for the manufacture of a three-dimensional object (2) by a solidification of a building material (18),

wherein the control unit (29) is configured to control the additive manufacturing device (1) such as to carry out a method according to claim 13.

15. A computer program comprising a sequence of instructions that enables a control unit (29) to carry out a method according to claim 13 when the computer program is loaded and executed in the control unit (29).

Fig. 1

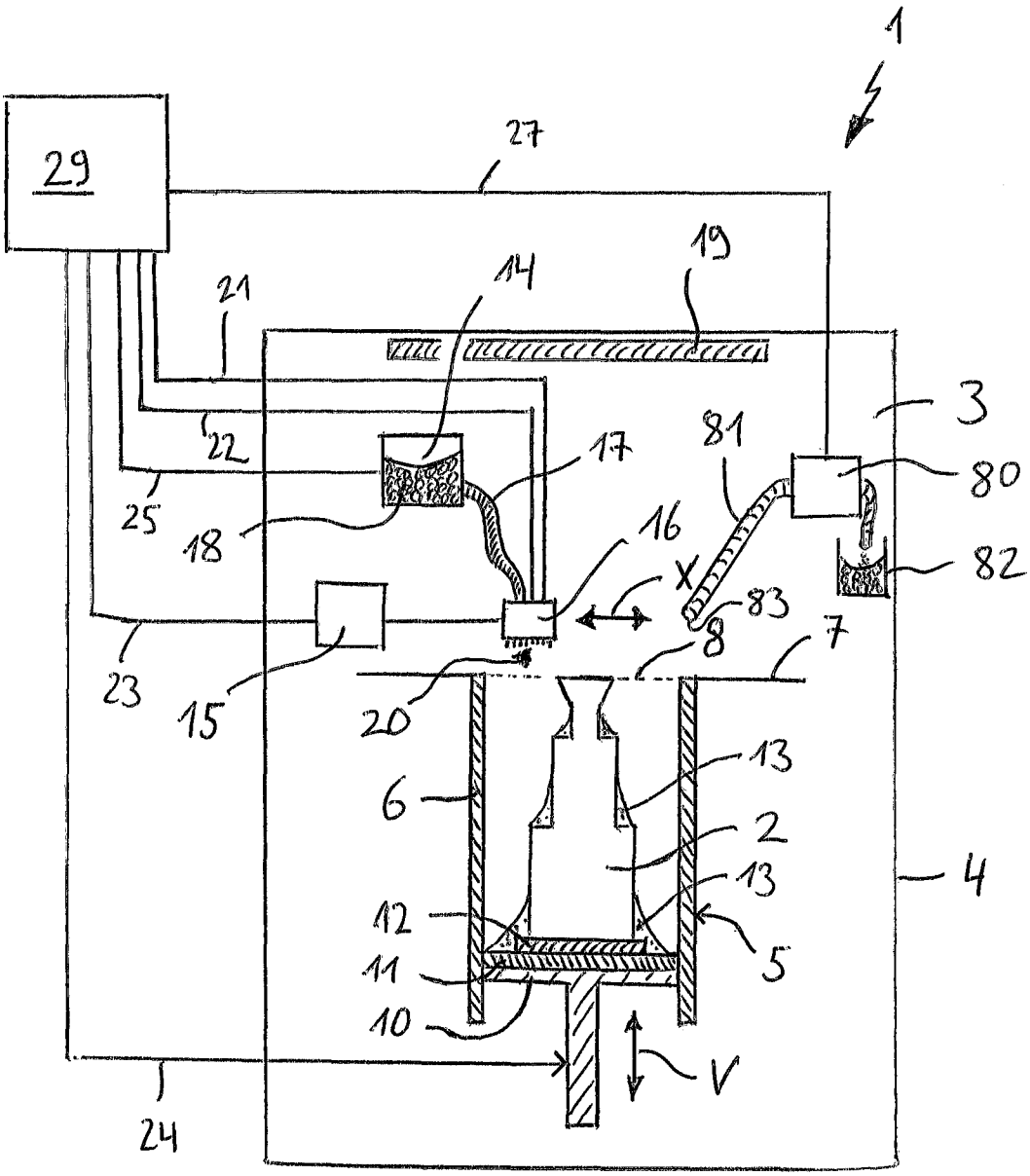

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81
3
80
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16
X
83
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4
12
13
5
11
10
V
24

Fig. 2

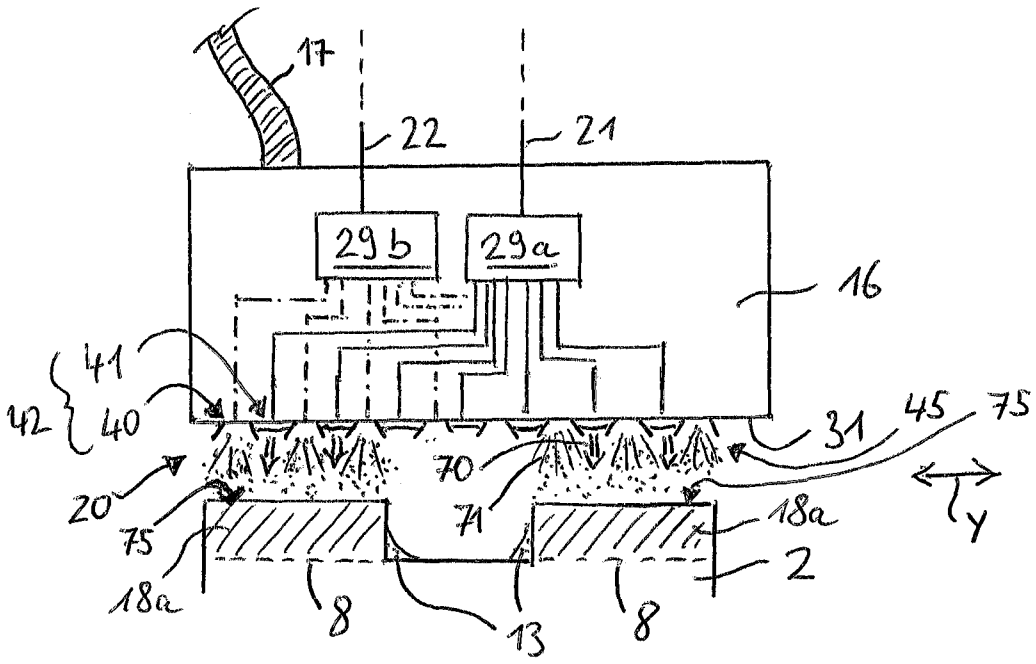

17
22
21
29b
29a
16
41
42
40
31
45
75
20
70
71
18a
75
Y
18a
2
8
13
8

Fig. 3

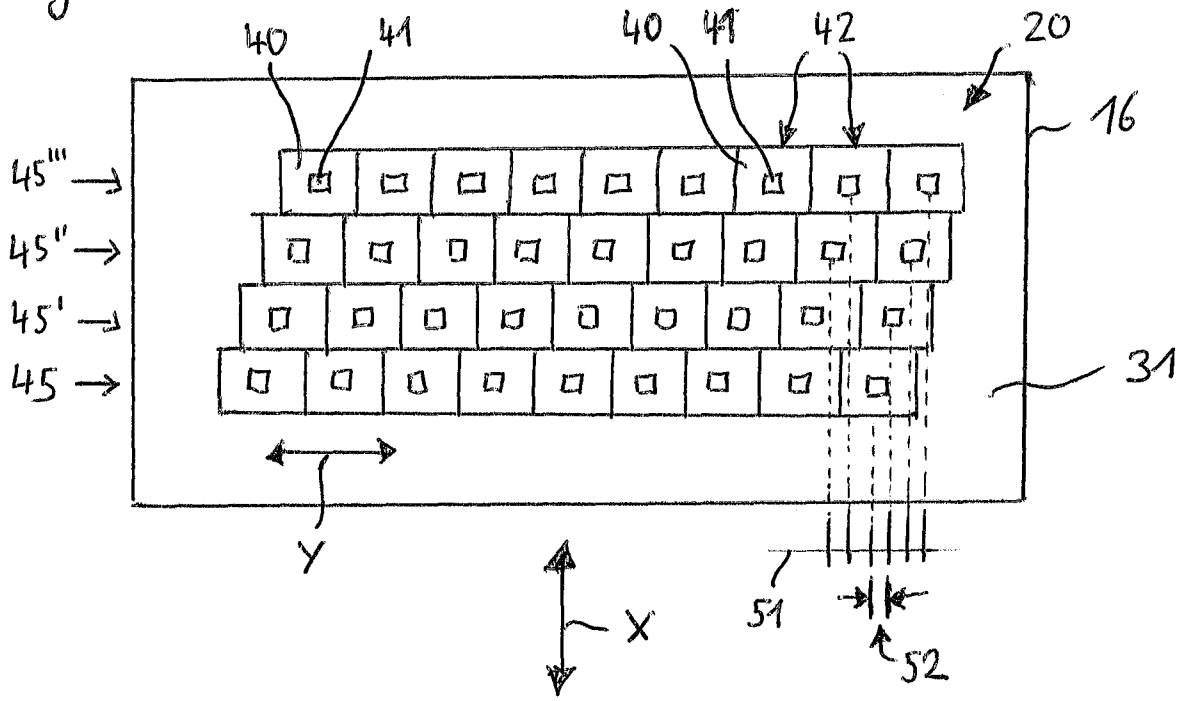

40
41
40
41
42
20
16
45'''
45''
45'
45
31
Y
X
51
52

Fig. 4

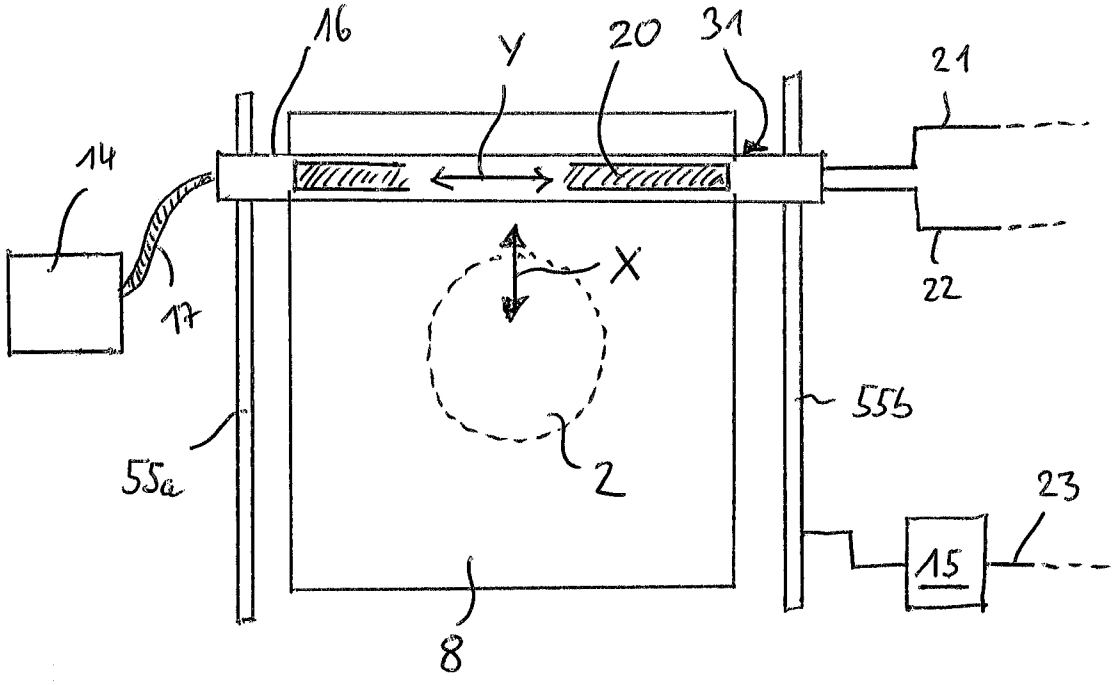
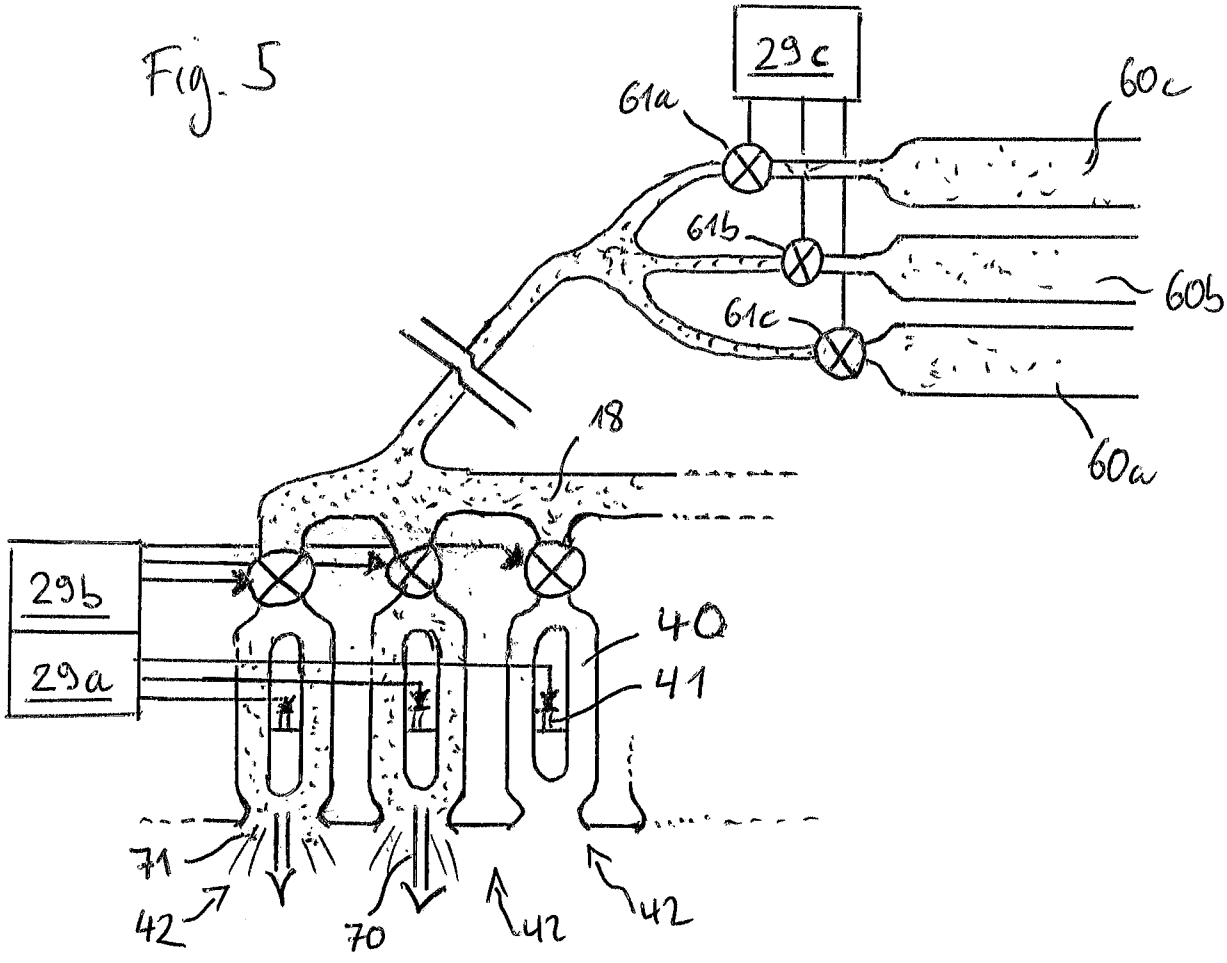

16
Y
20
31
21
14
17
X
22
55b
55a
2
23
15
8

Fig. 5


29c
61a
60c
61b
60b
61c
18
60a
29b
29a
40
41
71
42
70
42
42

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/084849

A. CLASSIFICATION OF SUBJECT MATTER
INV. B22F3/105 B33Y10/00 B33Y30/00 B33Y50/02 B29C64/153
B29C64/209 B29C64/255 B29C64/268 B29C64/277 B29C64/393
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)
B22F B33Y 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	EP 3 162 473 A1 (SEIKO EPSON CORP [JP])	1-4,7,8,
	3 May 2017 (2017-05-03)	10-15
Y	figures 1, 2, 3, 21	9
A	paragraph [0001]	5,6
	paragraph [0063] - paragraph [0066]	
	paragraph [0077] - paragraph [0082]	
	paragraph [0158]	
	paragraph [0176] - paragraph [0179]	

Y	EP 2 502 729 A1 (BAE SYSTEMS PLC [GB])	9
	26 September 2012 (2012-09-26)	
	cited in the application	
A	figures 1, 2	1-8,
	paragraph [0021] - paragraph [0022]	10-15

	-/--	

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

[X] See patent family annex.

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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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 August 2018	07/09/2018

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Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/084849

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 106 694 878 A (LUO TIANZHEN) 24 May 2017 (2017-05-24) *use of a machine translation* figure 1 description of figure 1; page 21 -----	1-15

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/084849

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		EP 3162473 A1	03-05-2017
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