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MANUFACTURING THREE-DIMENSIONAL
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(57) **ABSTRACT**

An apparatus and a method manufacture three-dimensional objects by selective solidification of a build material applied in layers. In order to improve the manufacturing process and in particular to optimize heat input, a heating element is provided that has at least two functional openings. One of the at least two functional openings serves as a material pass-through and another of the at least two functional openings serving simultaneously as a radiation pass-through.

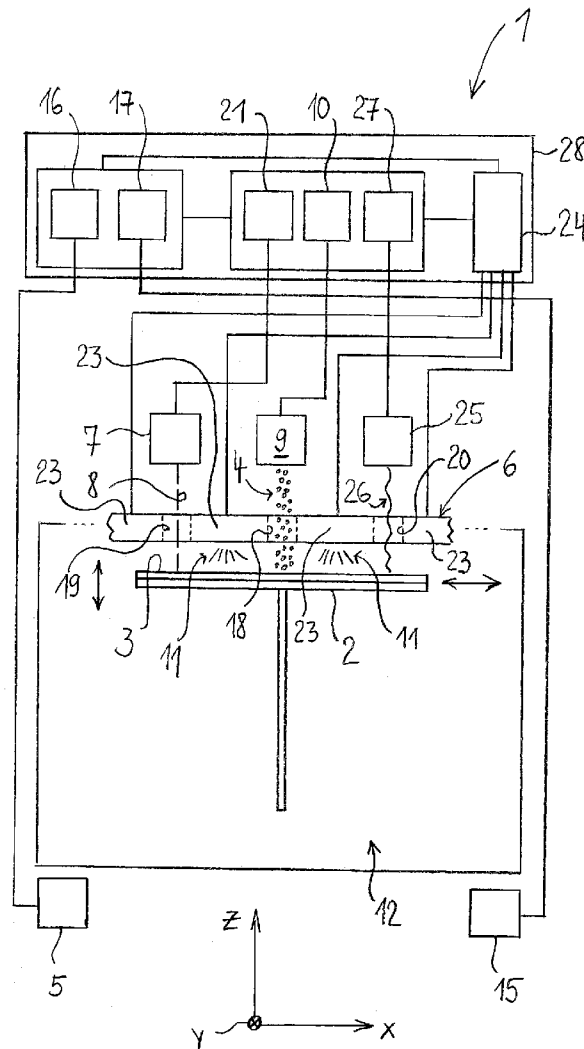


FIG. 1

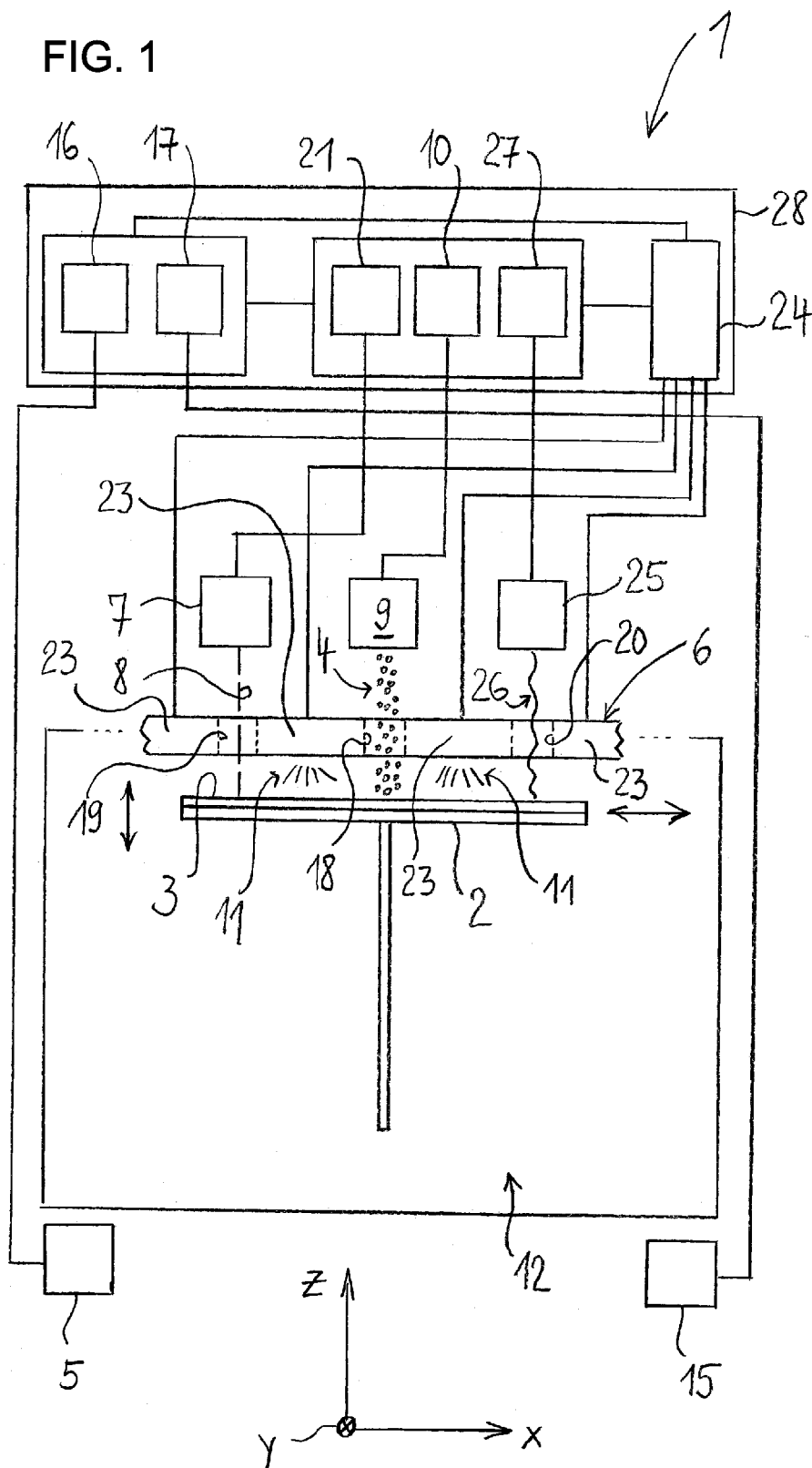
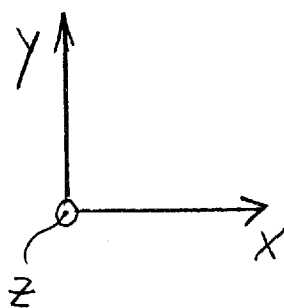
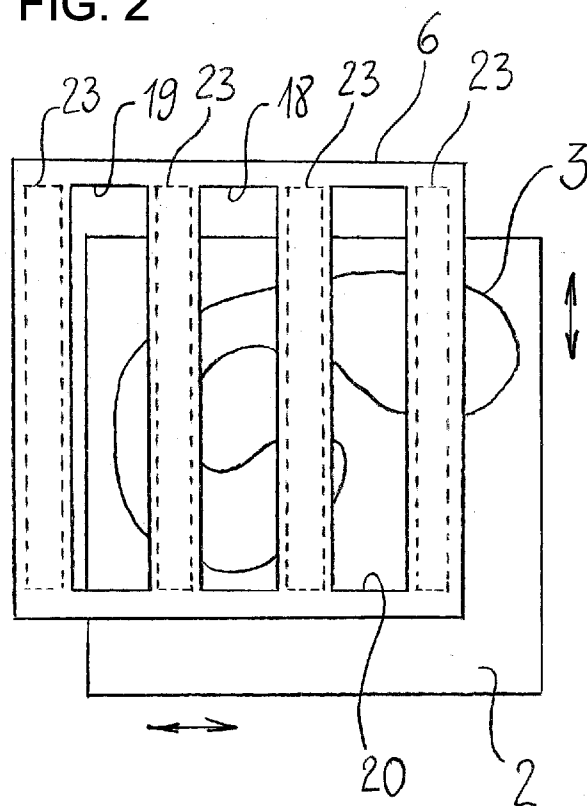
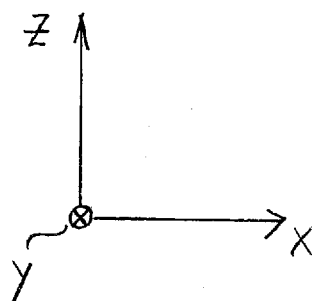


FIG. 2





APPARATUS AND METHOD FOR MANUFACTURING THREE-DIMENSIONAL OBJECTS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the priority, under 35 U.S.C. §119, of German application DE 10 2013 109 162.8, filed Aug. 23, 2013; the prior application is herewith incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The invention relates to an apparatus and a method for manufacturing three-dimensional objects by selective solidification of a build material applied in layers.

[0003] A large number of apparatuses and methods for manufacturing three-dimensional objects by selective solidification of a build material applied in layers are known from the existing art. Laser sintering or selective mask sintering, for example, may be recited here. Systems with which a layer manufacturing method of this kind can be carried out are also referred to as “rapid prototyping” systems. These layer manufacturing methods serve to manufacture components built up in layers from a solidifiable material such as resin, plastic, metal, or ceramic, and are used, for example, to produce engineering prototypes. Using an additive production method, three-dimensional objects can be manufactured directly from CAD data.

[0004] In a layer manufacturing method of this kind, the objects are built up in layers, i.e. layers of a build material are applied successively over one another. Before application of the respective next layers, the locations in the respective layers which correspond to the object to be manufactured are selectively solidified. Solidification is accomplished, for example, by local heating of a usually powdered layering of raw material using a radiation source. An exactly defined object structure of any kind can be generated by controlled introduction of radiation in a suitable fashion into the desired regions. The layer thickness is also adjustable. A method of this kind is usable in particular for the manufacture of three-dimensional bodies by successively generating multiple thin, individually configured layers.

[0005] The build material to be solidified is typically preheated to a temperature that is below the processing temperature. The processing temperature is then attained with the aid of an additional energy input.

[0006] In a laser sintering process, for example, a plastic material is preheated to a temperature below the sintering temperature. The energy introduced by the laser then contributes only the differential quantity of heat for fusing the powder particles.

[0007] Preheating is accomplished in many cases by heating the build platform. With this heating “from below,” however, the preheating heat flow decreases as the component height increases, due to losses and the increasing volume of the powder charge.

[0008] Other methods also result in an undesired irregular temperature distribution in the build material. This also applies in particular to those methods in which preheating is accomplished by heat delivery “from above.” Here devices that can be intermittently heated are placed above the build

layer. Complex systems for controlling the heat curve, and other laborious actions, are used in an attempt to achieve a uniform temperature distribution in the build material to be preheated.

SUMMARY OF THE INVENTION

[0009] An object of the present invention is to improve the manufacturing process, in particular to optimize heat input.

[0010] The invention proposes no longer pursuing the cycle-timed manufacturing procedure known from the existing art, in which, within one clock cycle, after an application of a material first a preheating action and then a selective solidification action occur before another material application is performed in a subsequent new clock cycle. The invention instead proposes a continuous manufacturing process in which application of the build material, preheating, and selective solidification occur simultaneously by local heating of the build material, specifically at different sites on the same objects to be manufactured or also on different objects simultaneously if multiple objects are being manufactured on the build platform.

[0011] The apparatus according to the present invention encompasses a build platform, arranged in an X-Y plane, on which at least one three-dimensional object is generated in layers. A heating element is provided which at least partly overlaps the build platform, for inputting thermal energy into the build material. The apparatus further has a drive device for generating a relative motion in an X-Y direction between the build platform and the heating element. The heating element contains at least two simultaneously usable functional openings, one of the at least two functional openings being embodied as a material pass-through and another of the at least two functional openings being embodied as a radiation pass-through.

[0012] The method according to the present invention correspondingly encompasses the steps of: generating the at least one three-dimensional object, in layers, on a build platform arranged in an X-Y plane; inputting thermal energy into the build material with the aid of a heating element at least partly overlapping the build platform; generating a relative motion in an X and/or Y direction between the build platform and the heating element by means of a drive device; and simultaneously causing the build material and the radiation energy to pass through the heating element using at least two functional openings.

[0013] A fundamental idea of the invention is the use of a heating element that serves to preheat the build material and is notable for functional openings that serve as a material pass-through and radiation pass-through, therefore as a coating opening for the application of the build material and as an exposure opening for local heating of the build material. When a heating element of this kind is moved in suitable fashion relative to the build platform, the application of the build material, the preheating, and the selective solidification can occur simultaneously, i.e. non-cycle-timed, uninterrupted manufacture of the at least one object. In other words, the object or objects is built up continuously, the build rate being determined by the relative motion between the build platform and heating element. The geometric arrangement of the object regions located in the various manufacturing process phases, in particular the spacing of the object regions from one another, is determined by the arrangement of the functional openings in the heating element, in particular by the spacing of the functional openings from one another.

[0014] For example, in a first object region the build material in the form of a freshly applied powder charge is being preheated by the heating element, while in a second object region arranged behind the first object region in the motion direction, a layer *n* currently being solidified with the aid of radiation energy penetrating through an exposure opening. At the same time, in a third object region that is located behind the second object region in the motion direction, post-heating of the build layer *n*, just previously solidified there, is being performed by the heating element, while in a fourth object region located behind the third object region, further build material for a subsequent layer *n*+1, introduced through a coating opening, is being applied onto the layer *n* that is already present. The object regions can be regions of one object or regions of different objects if multiple objects are arranged on the build platform.

[0015] Heat delivery for preheating is accomplished “from above,” so that the disadvantages of heat delivery via the build platform do not occur. At the same time, heat delivery is preferably accomplished not only intermittently, i.e. not only when the heating element is located (as in the existing art) above the build layer for a short time, but instead constantly, this being made possible by the novel continuous working mode. Optimization of heat input is thereby achieved in simple fashion. At the same time, the manufacturing process as a whole is improved.

[0016] At the same time, the present invention allows elimination of the need for a uniform temperature distribution. Because the manufacturing method has made different degrees of progress at different sites, different temperatures at different sites can be advantageous. For example, in one region a preheating temperature can be advantageous in order to prepare the build material for imminent local heating; in an adjacent region, on the other hand, a post-heating temperature can be present, as is advantageous for achieving certain properties of the already solidified layer, for example in order to prevent warping.

[0017] Because the heating element is constantly available, a defined inhomogeneous temperature distribution of this kind can be implemented in particularly simple fashion. In an advantageous embodiment of the invention, the heating element contains multiple regions capable of different temperature control. This is achieved, for example, with the aid of multiple mutually independently operable heating modules.

[0018] An additional heat source for furnishing thermal energy can also be provided, in particular in the form of a radiation source arranged above the heating element. In this case at least one of the functional openings is embodied as a heating opening for additional input of thermal energy. The heating opening can be a functional opening that already performs another function; for example, a radiation pass-through already serving as an exposure opening can serve at the same time as a heating opening.

[0019] An embodiment of the invention in which the heating element is of substantially plate-shaped configuration has proven to be particularly advantageous for the transfer of heating energy to the build material. The plate-like shape of the heating element simultaneously makes possible a particularly simple embodiment of the functional openings. Advantageously, the heating element and build platform are embodied in such a way that they overlap one another over the largest possible area, preferably completely, or can be caused during the manufacturing process to overlap one another over as large an area as possible, preferably completely.

[0020] In a preferred embodiment of the invention, the heating element is arranged above the build platform. In a variant, the heating element is spaced away from the respectively topmost build layer. Heating is accomplished by thermal radiation. In an alternative variant, the heating element touches the topmost build layer. Heating is then accomplished by thermal conduction.

[0021] If the build platform is located inside a process chamber that is closed in the operating state, the heating element can then serve as a demarcating wall of the process chamber. In other words, in this case the process chamber is closed off by the heating element. The heating element is then a part of the process chamber.

[0022] The coating opening is always an actual opening in the sense of a material perforation. For the exposure opening, however, the heating element need not necessarily be perforated. The exposure opening can also be embodied as a region of suitable material, in the basic body of the heating element, which is suitable for the passage of radiation.

[0023] In a preferred embodiment of the invention, radiation energy is introduced through the exposure opening but the opening is not completely illuminated. Instead, a targeted irradiation of the build material arranged below the opening occurs, within the boundaries of the opening. The radiation can derive from one or more radiation sources. For example, for local heating of the build material one or more laser beams can execute a linear back-and-forth motion inside the functional opening within the window furnished by the functional opening, or the laser beams are guided in defined fashion inside the window on a nonlinear trajectory, in each case as a function of the structure to be generated. The radiation is guided with the aid of a suitable control system. The build material, previously preheated to a temperature below the processing temperature, becomes locally heated further. The processing temperature is reached with the aid of this additional energy input.

[0024] In a simple variant of the invention, the arrangement and size of the functional openings is unmodifiable. It has proven advantageous, for example, to use strip-shaped functional openings that lie parallel to one another. The functional openings are advantageously arranged in the heating element perpendicularly to the direction of relative motion, for example perpendicularly to the X direction or Y direction. Alternatively, it is possible for the functional openings to be arranged obliquely, i.e. at an angle to the motion direction. It is advantageous in the context of the present invention that the shape, arrangement, and size of the functional openings can be adapted to the special aspects of the method. Instead of strip-shaped or slit-shaped functional openings, for example, orifice-shaped functional openings or functional openings of any other shape can also be provided for for all or for individual functions.

[0025] In an alternative variant, the shape, arrangement, and/or size of the functional openings is modifiable. For example, it can be advantageous to embody the size of the exposure opening modifiably, in particular when the functional opening serves as an aperture stop, i.e. to demarcate the cross section of the introduced radiation. It can likewise be advantageous to embody the size of the coating opening modifiably, in particular when the shape and/or size of the opening directly determine the application location or volume of build material applied for each unit time. A modification of the functional openings can also be accomplished in particular during runtime, i.e. while the manufacturing pro-

cess is in progress. Additional suitable drive and control devices are then to be provided for this as applicable.

[0026] It is not only heat input into the build material that is improved with the present invention. In addition, thanks to a suitable interaction of the arrangement and size of the functional openings and the relative motion between the heating element and build platform, and the manner in which radiation for local solidification of the build material is furnished and/or guided, the manufacturing process can also be carried out particularly efficiently.

[0027] This purpose is served by a central control system for the manufacturing process using a data model for description of the object to be manufactured with the aid of the layer building method. The control system encompasses all relevant operations of the manufacturing process that proceeds simultaneously at multiple sites in different manufacturing phases, i.e. manufacturing processes that have made different degrees of progress. In other words, control always occurs in accordance with the actual progress of the manufacturing process, using for this purpose sensor data of suitable sensors, in particular temperature sensors. The control system encompasses in particular control of the heating of the heating element, here optionally the defined control of individual temperature regions. The control system also encompasses control of the drive device for the relative motions between the heating element and the build platform, and control of the furnishing and/or application device for furnishing and/or applying the build material, and control of the guided radiation source(s) for local heating of the build material and, if applicable, control of the additional radiation source for controlling the temperature of the build material, as well as also, if applicable, control of the functional openings of modifiable arrangement and/or size.

[0028] All calculation operations necessary in connection with control of the layer manufacturing system and with execution of the method according to the present invention are performed by one or more data processing units that are embodied for carrying out the operations. Each of these data processing units preferably has a number of functional modules, each functional module being embodied to carry out a specific function or a number of specific functions in accordance with the method described. The functional modules can be hardware modules or software modules. In other words, insofar as it relates to the data processing unit the invention can be realized either in the form of computer hardware or in the form of computer software, or in a combination of hardware and software. If the invention is realized in the form of software, i.e. as a computer program product, all the functions described are implemented by computer program instructions when the computer program is executed on a computer having a processor. The computer program instructions are realized in any programming language in a manner that is known per se, and can be furnished to the computer in any form, for example in the form of data packets that are transferred via a computer network, or in the form of a computer program product stored in a diskette, a CD-ROM, or another data medium.

[0029] Other features which are considered as characteristic for the invention are set forth in the appended claims.

[0030] Although the invention is illustrated and described herein as embodied in an apparatus and a method for manufacturing three-dimensional objects, it is nevertheless not intended to be limited to the details shown, since various modifications and structural changes may be made therein

without departing from the spirit of the invention and within the scope and range of equivalents of the claims.

[0031] The construction and method of operation of the invention, however, together with additional objects and advantages thereof will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

[0032] FIG. 1 is a schematic diagram of an apparatus according to the invention having a highly simplified process chamber depicted in section;

[0033] FIG. 2 is a schematic plan view of a heating element disposed above a build platform; and

[0034] FIGS. 3A-3E are simplified sectioned depictions of layers of an object to be built up, in different manufacturing phases.

DETAILED DESCRIPTION OF THE INVENTION

[0035] All the figures show the invention not to scale, merely schematically, and only with its essential constituents. Identical reference characters correspond to elements having an identical or comparable function.

[0036] Referring now to the figures of the drawings in detail and first, particularly to FIGS. 1 and 2 thereof, there is shown an apparatus 1 for laser sintering, more specifically an apparatus for manufacturing at least one three-dimensional object by selective solidification of a build material applied in layers. The invention is not, however, limited to this specific method. The invention is also applicable to other additive production methods, for example laser melting, mask sintering, drop on powder/drop on bed, stereolithography, and the like.

[0037] An orthogonal coordinate system (X, Y, Z) is utilized in the description of the invention.

[0038] The apparatus 1 for laser sintering encompasses a build platform 2, disposed in an X-Y plane, on which a three-dimensional object 3 is generated in layers in known fashion. A build material 4 that is suitable is a plastic powder. After production of a layer n, in order to produce a new layer n+1 the build platform 2 having the already created and hardened layers is displaced downward over a specific travel length. This purpose is served by a drive device 5 for generating a relative motion in a Z direction, i.e. perpendicularly to the build plane, between the build platform 2 and a heating element 6 described later in further detail. The drive device 5 is, for example, an electric motor.

[0039] Between solidification of a layer n and application of new build material 4 for a subsequent layer n+1, provision can be made to remove excess build material 4 from the build platform 2. In this case a device suitable for this is provided, for example in the form of a non-illustrated wiping blade or the like, which advantageously is connected to or interacts with the heating element 6.

[0040] The apparatus 1 encompasses at least one radiation source 7 that furnishes radiation energy for local heating of the build material 4 in order to selectively solidify the latter. The at least one radiation source 7 is, for example, a laser that delivers a laser beam 8 in a guided fashion.

[0041] The apparatus 1 furthermore encompasses at least one furnishing and/or application device 9 with which the build material 4 is furnished and/or is applied onto the build platform 2 or onto a build layer that is already present. The

furnishing and/or application device 9 is, for example, a device for applying a powder charge. The furnishing and/or application device 9 is connected to a corresponding control system 10 that controls the application of material.

[0042] The apparatus 1 further encompasses the heating element 6 (already mentioned above) for introducing thermal energy into build material 4, which element constantly at least partly overlaps the build platform 2 during the manufacturing process. The heating element 6 is of a substantially plate-shaped configuration. It is arranged above the build platform 2, being spaced away from the respectively topmost build layer. The spacing is typically between 100 μm and 10 mm. The heating of the build material 4 is accomplished by thermal radiation 11 delivered by the heating element 6, as depicted symbolically in FIGS. 1 and 3.

[0043] The build platform 2 is located inside a process chamber 12, closed in the operating state, that is merely schematically indicated in FIG. 1. The heating element 6 serves here as a demarcation wall of the process chamber 12. More precisely, the heating element 6 is embodied as part of an upper cover 13 of the process chamber 12.

[0044] The apparatus 1 further encompasses a drive device 15 for generating a relative motion between the build platform 2 and the heating element 6 in the X and/or Y direction, i.e. in a layer direction. The drive device 15 is, for example, an electric motor. The two drive devices 5, 15 are connected to corresponding drive control systems 16, 17.

[0045] In the exemplifying embodiment described here, the drive device 15 moves the build platform 2 relative to the stationary heating element 6. The principal motion direction is the X direction. In the simplest case, the motion of the build platform 2 is limited to this principal motion direction. If necessary or advantageous for the manufacturing process, the motion in the X direction can be overlaid by a motion of the build platform 2 in the Y direction.

[0046] The heating element 6 contains at least two, in the example depicted in FIG. 1 three simultaneously usable functional openings 18, 19, 20 spaced apart from one another. The functional openings 18, 19, 20 are slit-shaped or strip-shaped, elongated rectangular, and lie parallel to one another and perpendicular to the principal motion direction, here the X direction. One of the functional openings is embodied as a material pass-through 18 and another of the functional openings as a radiation pass-through 19. During the production of the object 3, both the build material 4 and radiation energy, here in the form of the laser beam 8, are allowed to pass simultaneously through functional openings 18, 19.

[0047] Expressed differently, the one functional opening is embodied as a coating opening 18 for the application of the build material 4 onto the build platform 2 or onto a build layer that is already present, and the other functional opening is embodied as an exposure opening 19 for simultaneous introduction of the radiation energy of the at least one radiation source 7 into the applied build material 4 in order to solidify the build material 4.

[0048] Radiation energy for local heating of the build material 4 is introduced by guiding the laser beam 8 through the exposure opening 19 on a defined path. The laser beam 8 is guided with the aid of a suitable drive and a control device 21.

[0049] The heating element 6 contains multiple heating modules 23, to which control can be applied mutually independently and which are arranged between or next to functional openings 18, 19, 20. All the heating modules 23 of the heating element 6 are connected to a heating control system

24. The working principle of the heating modules 23 is based, for example, on the principle of electrical induction. Other suitable functioning modes for the heating modules are likewise possible.

[0050] In the example illustrated in FIG. 1, the apparatus 1 also encompasses an additional heat source in the form of a radiation source 25, arranged above the heating element 6, for furnishing thermal energy. The additional radiation source 25 is, for example, an infrared radiator that delivers infrared radiation 26. A suitable control system 27 is provided for this radiation source as well. The additional radiation source 25 has associated with it a dedicated functional opening 20 that thus serves as a heating opening.

[0051] A central control system 28 is responsible for controlled execution of the manufacturing method. The control system 28 encompasses for this purpose all the relevant control sub-systems 10, 16, 17, 21, 24, 27.

[0052] Various phases of manufacture will be described below with reference to FIGS. 3A-3E. What is used here is a heating element 6', different from heating element 6 shown in FIGS. 1 and 2, which possesses three functional openings, namely two coating openings 18, 18' and one exposure opening 19 arranged between the coating openings 18, 18'.

[0053] In FIG. 3A, the build platform 2, driven by the drive device 15, moves through in the X direction beneath first coating opening 18 of the heating element 6. The build material 4 for a layer n becomes deposited onto the build platform 2.

[0054] In FIG. 3B, the build platform 2 moves farther in the X direction. The build material 4 that was applied shortly beforehand becomes preheated, by the heating module 23 arranged between the first coating opening 18 and the exposure opening 19 in the basic body of the heating element 6, to a temperature below the sintering temperature. At the same time, in an adjacent object region preheated just previously, additional thermal energy is introduced with the aid of laser beam 8 through the exposure opening 19, with the result that the powder particles fuse.

[0055] In FIG. 3C, the build platform 2 moves farther in the X direction. Before the build platform 2 reaches the second coating opening 18', it is moved a requisite travel distance downward in the Z direction, driven by the drive device 5. The build material 4 for a further layer n+1 is applied through second coating opening 18'. This object region had just previously been heated again by a further heating module 23' arranged between the exposure opening 19 and the second coating opening 18'.

[0056] In FIG. 3D, the build platform 2 has reached its one reversal point. Layers n and n+1 have been generated. Because there is no longer an exposure opening 19 located above the build platform 2, at this moment laser irradiation is no longer taking place. The application of the build material 4 also occurs only as long as at least one of the two coating openings 18, 18' is arranged above the build platform 2.

[0057] In FIG. 3E, the build platform 2 moves through beneath the heating element 6 in the X direction, oppositely to the first motion. With the aid of the second coating opening 18', a new application of material for the next layer n+2 has already occurred, as has preheating with the aid of a third heating module 23". The build platform 2, driven by the drive device 5, has previously been moved down again a necessary distance in the Z direction. A local irradiation with the laser beam 8 occurs through the exposure opening 19 in order to solidify the structure to be generated. First the heating module

23 serves for post-heating. Upon a further motion of the build platform **2**, an application of material for layer $n+3$ will occur shortly through the first coating opening **18**.

[0058] All features presented in the specification, the claims below, and the drawings can be essential to the invention both individually and in any combination with one another.

[0059] The following is a summary list of reference numerals and the corresponding structure used in the above description of the invention:

- [0060] **1** Apparatus for laser sintering
- [0061] **2** Build platform
- [0062] **3** Object
- [0063] **4** Build material
- [0064] **5** Drive direction (Z)
- [0065] **6** Heating element
- [0066] **7** Radiation source, laser
- [0067] **8** Laser beam
- [0068] **9** Furnishing/application device
- [0069] **10** Control system for material application
- [0070] **11** Thermal radiation
- [0071] **12** Process chamber
- [0072] **13** Cover
- [0073] **14** (unassigned)
- [0074] **15** Drive device (X/Y)
- [0075] **16** Drive control system (Z)
- [0076] **17** Drive control system (X/Y)
- [0077] **18** Functional opening, material pass-through, coating opening
- [0078] **19** Functional opening, radiation pass-through, exposure opening
- [0079] **20** Functional opening, heating opening
- [0080] **21** Drive and control device for laser
- [0081] **22** (unassigned)
- [0082] **23** Heating module
- [0083] **24** Heating control system
- [0084] **25** Radiation source, IR radiator
- [0085] **26** Infrared radiation
- [0086] **27** Control system for additional heating
- [0087] **28** Central control system

1. An apparatus for manufacturing three-dimensional objects by selective solidification of a build material applied in layers, the apparatus comprising:

- a build platform, disposed in an X-Y plane, on which at least one three-dimensional object is generated in layers;
- a heating element, at least partly overlapping said build platform, for inputting thermal energy into the build material, said heating element having at least two simultaneously usable functional openings formed therein,

wherein one of said at least two functional openings being a material pass-through and another of said at least two functional openings being a radiation pass-through; and

a drive device for generating a relative motion in an X-Y direction between said build platform and said heating element.

2. The apparatus according to claim **1**, wherein said heating element constantly at least partly overlaps said build platform.

3. The apparatus according to claim **1**, wherein said heating element and said build platform can be caused to overlap one another completely.

4. The apparatus according to claim **1**, wherein said heating element is of a substantially plate-shaped configuration.

5. The apparatus according to claim **1**, wherein said heating element is disposed above said build platform and either is spaced away from a topmost build layer or touches the topmost build layer.

6. The apparatus according to claim **1**, further comprising a process chamber, said build platform is disposed inside said process chamber that is closed in an operating state, and said heating element serving as a demarcating wall of said process chamber.

7. The apparatus according to claim **1**, wherein said heating element contains regions capable of different temperature control.

8. The apparatus according to claim **1**, wherein a shape of said functional openings is modifiable.

9. The apparatus according to claim **1**, further comprising an additional heat source embodied to furnish the thermal energy, wherein one of said at least two functional openings is embodied simultaneously or exclusively as a heating opening for additional input of the thermal energy.

10. A method for manufacturing three-dimensional objects by selective solidification of a build material applied in layers, which comprises the steps of:

- generating at least one three-dimensional object, in layers, on a build platform disposed in an X-Y plane;
- inputting thermal energy into the build material via a heating element at least partly overlapping the build platform, wherein the heating element, using at least two functional openings, allowing the build material and radiation energy to pass through simultaneously; and
- generating, via a drive device, a relative motion in an X and/or Y direction between the build platform and the heating element.

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