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(54) **Title**: A METHOD FOR ADDITIVE MANUFACTURING OF A SPATIAL 3D OBJECT AND A DEVICE FOR ADDITIVE MANUFACTURING OF A SPATIAL 3D OBJECT

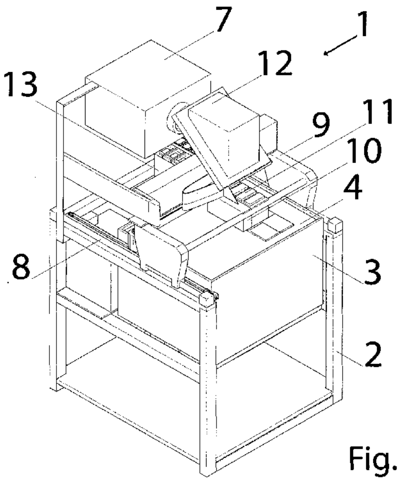

Fig.1

(57) **Abstract**: The invention provides a method for additive manufacturing of a spatial 3D object and a device for additive manufacturing of a spatial 3D object, in particular for printing three-dimensional objects in color. A method for additive manufacturing of a spatial 3D object, in which subsequent layers are formed by solidifying a surface layer of a liquid medium on a model base (5), where a formed layer is cured and a further layer is formed thereon after the 3D object being built is moved along with the model base (5). In a further layer color is applied and the layer with the color applied is finally cured. A device 1 for additive manufacturing of a spatial 3D object, comprising a frame (2), a tank (3) with a liquid photoactive medium (4), arranged in the frame, a model base (5), arranged within the tank (3) and movable vertically by means of an elevating system (6), and a light source (7). In the frame (2), on guides (8), a printing head (10) is mounted.

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A method for additive manufacturing of a spatial 3D object and a device for additive manufacturing of a spatial 3D object

The present invention provides a method for additive manufacturing of a spatial 3D object and a device for additive manufacturing of a spatial 3D object, in particular for printing three-dimensional colored objects.

Spatial printing or 3D printing of three-dimensional objects in color is presently broadly used and one of such uses involves faster designing operations that make it possible to produce prototype elements by spatial printing based on a digital model that is machine generated and stored.

This invention provides general improvements in a method and device for forming three-dimensional objects of a liquid medium, in particular in color, by means of stereolithography methods, involving use of lithography techniques, to produce three-dimensional objects, where such objects can be formed faster, reliably precisely and economically.

It is a common practice in manufacturing parts of plastics, and in construction processes, which is the first-time construction of such parts, and then carefully forming of a prototype. All the known methods entail considerable time and effort as well as costs.

The project is subsequently analyzed and this is often a laborious process repeatedly performed until the construction becomes optimized. After design optimization, the subsequent step is production. Plastics-based production is effected by injection method. Design costs and equipment costs are very high, and plastics parts are usually practically feasible solely in a large scale batch production.

In recent years, very complex techniques have been developed for forming three-dimensional objects in a liquid medium which is selectively cured by a visible radiation beam.

From the US patent specification US 4575330 a system is known for forming three-dimensional objects where digital cross-sections of the object being formed are built, which cross-sections can be created on a surface layer of a liquid that is capable to change its state of aggregation in response to suitable synergistic stimulation by a guided light radiation, particle bombardment or chemical reaction of successively adhering films constituting discrete subsequent adjoining object cross-sections and automatically integrating them together so as to ensure gradual laminar growth of the object being formed, where the three-dimensional object is formed and drawn from a substantially flat surface in the liquid medium during the forming process.

According to the prior art additive manufacturing of a spatial 3D object, subsequent layers of the object are formed by solidifying the surface layer of a liquid medium subject to curing in response to external factors such as light with certain parameters, for example wavelength or intensity. To such light specific regions of a thin layer of liquid medium are exposed and this causes curing of solely such exposed regions corresponding to a digital cross-section of the object being printed. Upon curing of this layer of the model being built, a further layer constituting a further next digital cross-section of the model being built is formed by curing.

In the solutions of the prior art also devices are used that enable carrying out the method presented above for preparing spatial 3D models. In the known devices for additive manufacturing of a spatial 3D object, in a frame constituting a body of the device, an operational tank is provided in which a liquid medium is housed said medium being a liquid photoactive material curable with light of some specific parameters. Such liquid photoactive material is cured only in regions that are within an area covered by the incident light. The remaining regions of the photoactive material remain uncured and during removal of the model from the tank such uncured liquid material flows off the model into the tank.

In order to cure the liquid photoactive material, it is exposed in a predetermined manner to light from a source of light, and thus the device has to be equipped with such a source of light. The source of light may be a computer-controlled DLP (Digital Light Processing) projector or a computer-controlled laser. Due to practical reasons, light from the source of light is directed suitably by means of a reflector or a set of reflectors, for example, for changing the incidence of light beams from horizontal into vertical. This may contribute to decrease in the height of the device and thus to making it more compact.

As mentioned above, a 3D spatial model is created by forming its subsequent layers "from the bottom", where such layers are determined by a digital form obtained from a computer system in the course of developing spatial design of the model.

In order to prepare a layer in the tank with liquid photoactive material a light-impermeable model base is arranged. The model base is connected to an elevating system positioned under the tank and enabling movement of the model base within the tank with liquid photoactive material.

Known devices do not enable coloring 3D models being built in a sufficient manner. In such devices this is in practice possible solely by means of selecting liquid photoactive materials in respective colors. It is also possible to paint the external surface of the prepared model after it is removed from the device, in another technological process.

It is the object of this invention to provide a method and a device that would alleviate drawbacks and disadvantages of the methods and devices known from the prior art, and to offer new methods and devices in this field of art.

This invention provides a method for additive manufacturing of a spatial 3D object, where subsequent layers are formed by solidifying a surface layer of a liquid medium on a model base. Such formed layer is cured and a further layer is formed thereon after the 3D object being built is moved along with the model base. In the inventive method on the further layer color is applied and the layer with the color applied is finally cured.

Preferably, a further layer is pre-cured before color application.

Also preferably, color is applied by means of an ink head.

Also preferably, color is applied by means of an ink head comprising cartridges with a set of CMYK colors palette.

Also preferably, color is applied solely onto preselected portions of the layer.

Preferably, further layers are formed by stereolithography (SLA).

Preferably, layers are cured by means of a light source in a form of a controlled DLP (Digital Light Processing) projector.

Also preferably, layers are cured by means of a controlled DLP (Digital Light Processing) projector with the use of a reflector.

Also preferably, light intensity of the DLP projector is adjusted.

Also preferably, layers are cured by means of a light source in a form of a laser controlled by a computer program.

Also preferably, layers are cured by means of a laser with the use of a reflector.

Also preferably, laser light intensity is adjusted.

Also preferably, upon final curing of the layer, the model base is lowered by a distance larger than the thickness of the further layer, and then it is elevated to a level corresponding to the thickness of the further layer.

It is another object of this invention to provide a device for additive manufacturing of a spatial 3D object, comprising a frame being a body of the device. Within the frame, a tank with liquid photoactive material is arranged. In the tank, a model base is arranged which base is movable vertically by means of an elevating system. The device is equipped with a light source that cures the liquid photoactive material. In the frame, a printing head is mounted in guides.

Preferably, the printing head is provided with at least one cartridge that comprises a coloring agent.

Preferably, the printing head is a thermal head.

Preferably, the printing head is a piezoelectric head.

Preferably, the printing head is a memjet-type head.

Preferably, the printing head is positioned on a carriage mounted in the frame of the device.

Preferably, the light source constitutes a DLP (Digital Light Processing) projector.

Also preferably, the light source constitutes is a laser controlled by a computer program.

Also preferably, the light source is provided with a reflector.

Also preferably, the device is equipped with a parking station for the printing head.

Preferably, the parking station for the printing head is provided with a liquid sprinkler for washing the printing head and a container for used washing liquid and for ink.

The object of the invention is illustrated in a non-limiting embodiment in the drawing, where: Fig. 1 shows a device for additive manufacturing a 3D object, in a side perspective view; Fig. 2 is a scheme of a device connected to a control computer; Fig. 3 shows a portion of a device showing a printing head; Fig. 4 shows a portion of a device in a perspective view showing the moment when color is applied by a printing head; Fig. 5 shows a device in a perspective view showing a head in its position in a parking station; Fig. 6 shows a portion of a device in a perspective view showing exposition of a layer of a liquid photoactive material after color application; Fig. 7 shows a tank with a model base in its upper position in a perspective view; Fig. 8 shows a tank in a perspective view showing an elevating system in an upper position of a model plate; Fig. 9 shows a tank with a model base in a lower position in a perspective view; Fig. 10 shows a tank in a perspective view showing an elevating system in a lower position of a model plate; Fig. 11 shows color application by means of a printing head on a pre-cured layer; and Fig. 12 is a schematic view of two adjacent layers with applied colors.

As shown in Fig. 1, a basis of a device 1 for additive manufacturing of a spatial 3D object constitutes a body in a form of a spatial frame 2 made of metal sections. In the frame 2 of the device 1 a tank 3 of a special structure is accommodated. In the tank 3 a photoactive material 4 is housed that reacts in response to light and undergoes light-induced curing. The photoactive material 4 in the tank 3 of the device 1 may undergo light-induced curing at varied extent determined by the parameters of the incident light. With a low light intensity value, it can thus undergo gelation only to a jelly form, or with a suitably high light energy it may become entirely cured. Between the liquid state and the entirely cured state of the photoactive material 4 numerous intermediate states may thus occur which are used when necessary.

In the tank 3 a model base 5 is arranged on which a 3D model is built from the photoactive material 4 by forming its subsequent layers. The model base 5 is positioned on an elevating system 6 which is constituted by a transmission assembly with worm guides connected to a step motor. The elevating system 6 is intended to elevate and lower the model base within the tank 3 with photoactive material 4.

In the upper part of the frame 2, in an extension arm, a light source 7 is mounted, which is constituted by a DLP (Digital Light Processing) projector. The light from a lamp in the DLP projector is projected onto a set of controllable miniature reflectors. In this way a monochromatic image is created for a specific layer of the 3D model being built, which image may be projected onto a layer of the photoactive material 4, over the model base 5.

The DLP projector that constitutes a light source 7 is mounted in the frame 2 so that the light beams emitted thereby are directed substantially horizontally. In order to direct these light beams onto a surface of the liquid photoactive material 4, the device 1 is equipped with a reflector 12 arranged in the frame 2 opposite the light source 7. The reflector 7 is a plane mirror that changes the direction of the beams from the DLP projector from horizontal into vertical.

In the upper part of the frame 2 of the device 1, along the sides of the tank 3, guides 8 are arranged, along which a carriage 9 may move horizontally along the sides of the tank 3. In the carriage 9 a printing head 10 is arranged that is movable horizontally between the guides 8 perpendicularly to the direction of movement of the carriage 9. The printing head 10 is thus movable in two directions that define a horizontal plane relative to the upper surface of the tank

3. This enables printing jets (not shown) to be positioned at any point over the model base 5 placed in the tank 3.

An outer edge of the frame 2 of the device 1 between the edges along which the guides 8 are arranged is provided with a parking station 13 for the printing head 10. The parking station 13 is equipped with a washing sprinkler (not shown) the purpose of which is to wash the printing head 10 after the color application operation. The parking station 13 is also equipped with a container 14 for used cleaning liquid and for ink used in the color application process.

The printing head 10 comprises four cartridges 11 with dyes in varied colors that make it possible to obtain a very broad variety of printable colors as a result of combining colors from different cartridges.

As shown in Fig. 2, the device 1 for additive manufacturing of a spatial 3D object, in this embodiment, is controlled by a computer system which houses a digital form of the 3D object being built. Thus a computer program controls operations of substantially all the subassemblies of the device 1, and in particular positioning of the model base 5, light source 7 in a form of a DLP projector, movement of the printing head 10 and color application effected thereby, as well as washing process of the printing head 10 in the parking station 13.

Fig. 3 shows an operating mechanism of the printing head 10, where all the mechanism elements of this embodiment are clearly shown. Thus the guides 8 arranged along the opposite sides of the tank 3 of the device 1 are shown, and a carriage 9 in which the printing head is moved perpendicularly to the guides 8.

If the device 1 for additive manufacturing of a spatial 3D object is not located in a darkroom, then it may be encased in a housing (not shown) which is light-impenetrable to avoid unintended exposition of the photoactive material 4 housed in the tank 4.

Fig. 7, Fig. 8, Fig. 9 and Fig. 10 show how the model base 5 is positioned in the tank and how it is movable within the tank 3. Also shown is an exemplary mechanism of the elevating system 6, configured with a step motor. The step motor in this solution is advantageous due to small steps of the model base 5 that may be 0.01 mm or more.

Fig. 7 and Fig. 8 show the model base 5 in an upper position within the tank 3 with the photoactive material 4, viewed from the bottom of the tank 3 and from the top of the tank 3.

Fig. 9 and Fig. 10 show the model base 5 in an upper position within the tank 3 with the photoactive material 4, viewed from the bottom of the tank 3 and from the top of the tank 3.

It will be appreciated that the elevating system 6 shown in this embodiment, with the use of a step motor, may be replaced with another solution that fulfills the same functions as for example a solution with a scissor linkage.

Drawing of Fig. 4 Fig. 5, Fig. 6 shows sequential steps of applying colors in a method for additive manufacturing of a spatial 3D object. The method of the invention is carried out by means of the following sequence of steps.

A model base 5 arranged in a tank 3 and immersed in a photoactive material 4 is elevated by means of an elevating system 6 to a level corresponding to immersion of the model base 5 in the photoactive material 4 at a thickness of a layer of the photoactive material 4 subject to treatment. This layer is pre-cured, in this embodiment, so it acquires a jelly consistence. On the pre-cured layer, color is applied by means of a printing head 10 for spraying ink from the respective set of cartridges 11. This is shown in Fig. 4, which illustrates the printing head 10 with a set of cartridges 11 above the tank 3 with the photoactive material 4. Following color application on the layer being built, the printing head 10 is moved to a parking station 13, where the printing head 10 is washed with a washing liquid supplied by a sprinkler. Used washing liquid, along with residual ink, is collected in a container 14.

As show in Fig. 6, the layer of the additively manufactured spatial 3D object being built is then finally cured. With this layer completed, the device 1 initiates forming a successive layer, if the preceding layer was not the last one. Forming of the successive layer may be limited to its curing without applying color by the printing head 10, if not necessary. Such case may be when this layer is not, for example, visible in the final 3D object. Accordingly, not every subsequent layer in the method of the invention has to be subject to coloring, and selection of the colored layers does not have to be cyclic, namely it is not required to color layers in a regularly defined order, for example every third or sixth layer.

It is also possible to apply color only to parts of the layer being built, for example only at its outer edges visible from the outside of the formed 3D object.

The photoactive material 4 used to form additively a spatial 3D object may be transparent or white. Selection of a photoactive material 4 proper for a specific spatial 3D object causes that the obtained 3D object may be transparent with a colorless photoactive material 4 or opaque with a white photoactive material 4. This is important for the final appearance of the finished 3D object formed by a method for additive manufacturing a spatial 3D object. When the photoactive material 4 is transparent, some special visual effects may be obtained for such object, where its internal structures may be visible in different colors.

As mentioned above, a layer being built may be pre-cured before color application. Pre-curing causes that ink does not spread in the entire volume of the layer being built but solely at the place where it is applied, as shown in Fig. 11 and Fig. 12. Although layers 100 and 101 shown in Fig. 12 are cured, solely their portions indicated as k1 and k2 are colored.

It is possible to obtain other effects in absence of pre-curing of a layer being built. Application of suitably atomized ink may cause an effect, upon curing, of ink droplets confined within the layer.

The above indicated embodiments of the invention, related both to a method for additive manufacturing of a spatial 3D object and to a device for additive manufacturing of a spatial 3D object, are provided herein solely as non-limited indications of the invention and they are not intended to limit the scope of protection sought as defined in the patent claims.

Claims

1. A method for additive manufacturing a spatial 3D object, where subsequent layers are formed by solidifying a surface layer of a liquid medium on a model base, where a formed layer is cured, and a further layer is formed thereon after the 3D object being built is moved along with the model base, **characterized by**
   - applying color on such further layer,
   - finally curing the layer with color applied.
2. A method according to claim 1 **characterized in that** a further layer is pre-cured before color application.
3. A method according to claim 1 **characterized in that** color is applied by means of an ink head (10).
4. A method according to claim 3 **characterized in that** color is applied by means of an ink head (10) comprising cartridges (11) with a CMYK colors palette.
5. A method according to claim 1 **characterized in that** color is applied solely onto preselected portions of a layer.
6. A method according to claim 1 **characterized in that** further layers are formed by stereolithography (SLA).
7. A method according to claim 1 **characterized in that** layers are cured by means of a light source (7) in a form of a controlled DLP (Digital Light Processing) projector.

8. A method according to claim 7 **characterized in that** layers are cured by means of a controlled DLP (Digital Light Processing) projector with the use of a reflector (12).
9. A method according to claim 7 **characterized in that** light intensity of the DLP projector is adjusted.
10. A method according to claim 1 **characterized in that** layers are cured by means of a light source (7) in a form of a laser controlled by a computer program.
11. A method according to claim 10 **characterized in that** layers are cured by means of a laser with the use of a reflector (12).
12. A method according to claim 10 **characterized in that** laser light intensity is adjusted.
13. A method according to claim 1 **characterized in that** upon final curing of the layer, the model base (5) is lowered by a distance larger than the thickness of a further layer, and then it is elevated to a level corresponding to the thickness of the further layer.
14. A device for additive manufacturing of a spatial 3D object, comprising a frame, a tank with a liquid photoactive medium arranged in the frame, a model base arranged in the tank and movable vertically by means of an elevating system, and a light source, **characterized in that** in the frame (2) on guides (8) a printing head (10) is mounted.
15. A device according to claim 14 **characterized in that** the printing head (10) is provided with at least one cartridge (11) comprising a coloring agent.
16. A device according to claim 14 **characterized in that** the printing head (10) is a thermal head.
17. A device according to claim 14 **characterized in that** the printing head (10) is a piezoelectric head.

18. A device according to claim 14 **characterized in that** the printing head (10) is a memjet-type head.
19. A device according to claim 14 **characterized in that** the printing head (10) is positioned on a carriage (9) mounted in the frame (2) of the device (1).
20. A device according to claim 14 **characterized in that** the light source (7) constitutes a DLP (Digital Light Processing) projector.
21. A device according to claim 14 **characterized in that** the light source (7) constitutes a laser controlled by a computer program.
22. A device according to claim 14 **characterized in that** the light source (7) is provided with a reflector (12).
23. A device according to claim 14 **characterized in that** it is equipped with a parking station (13) of the printing head (10).
24. A device according to claim 23 **characterized in that** the parking station (13) the printing head (10) is provided with a liquid sprinkler for washing the printing head (10) and with a container (14) for used washing liquid and for ink.

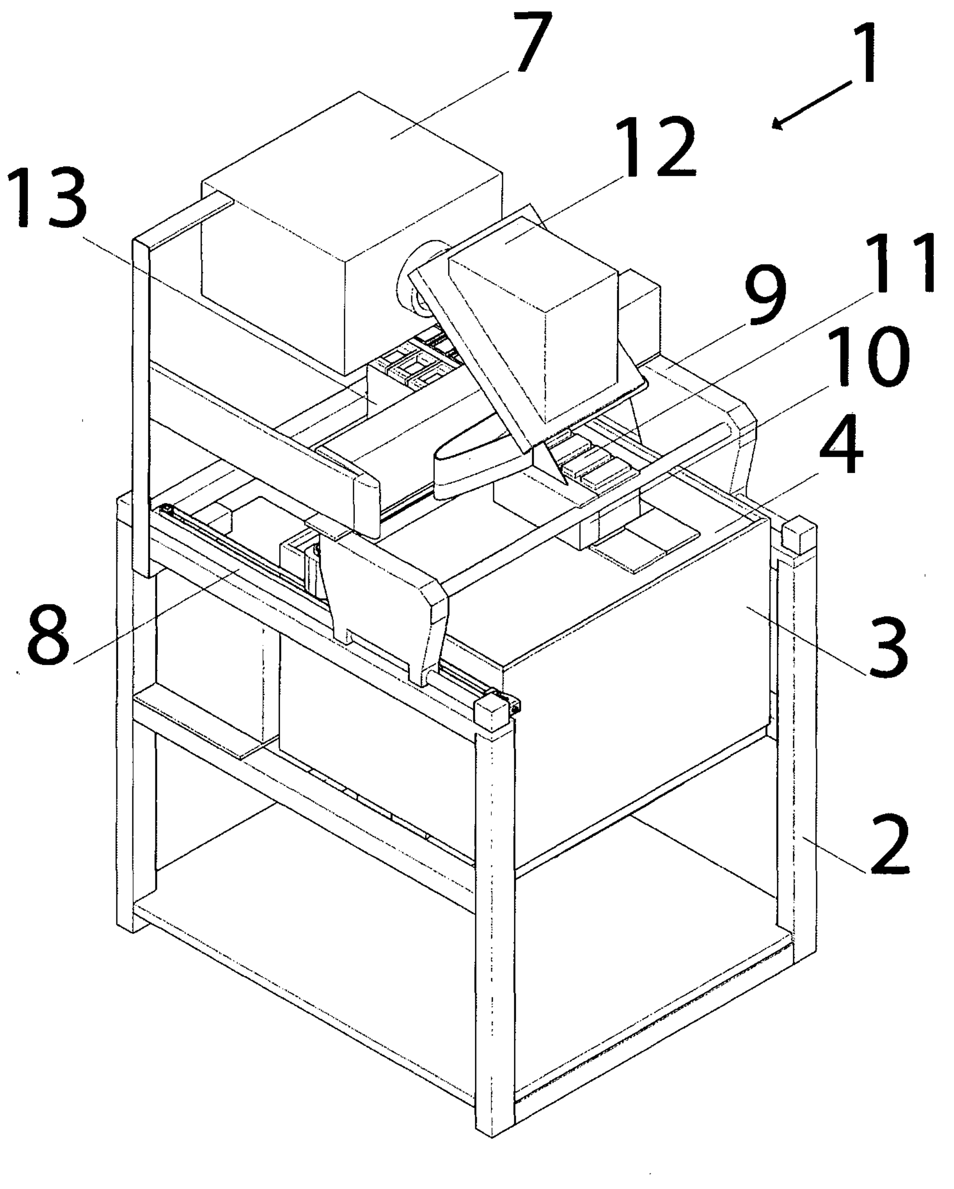

Fig.1

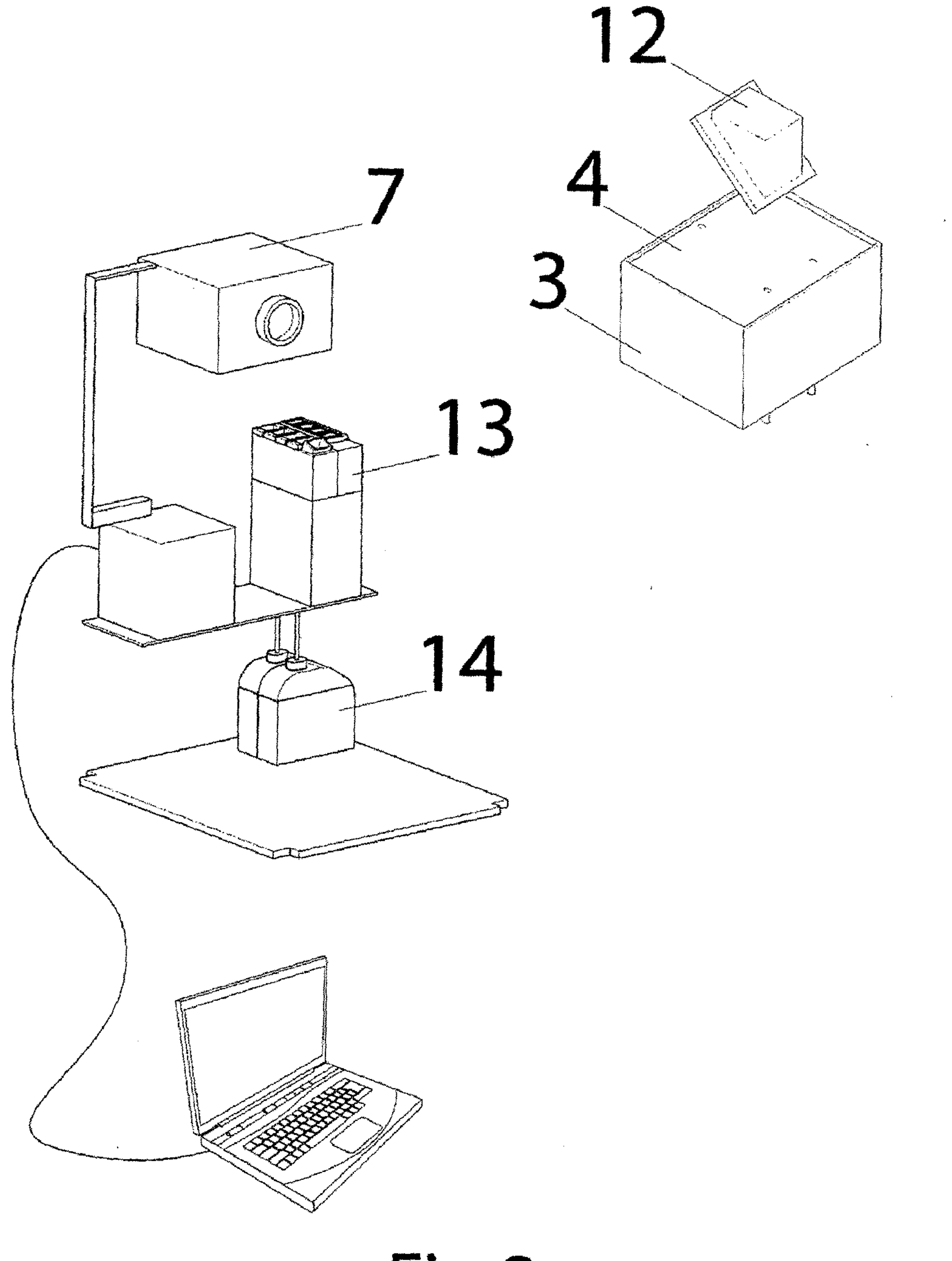

Fig.2

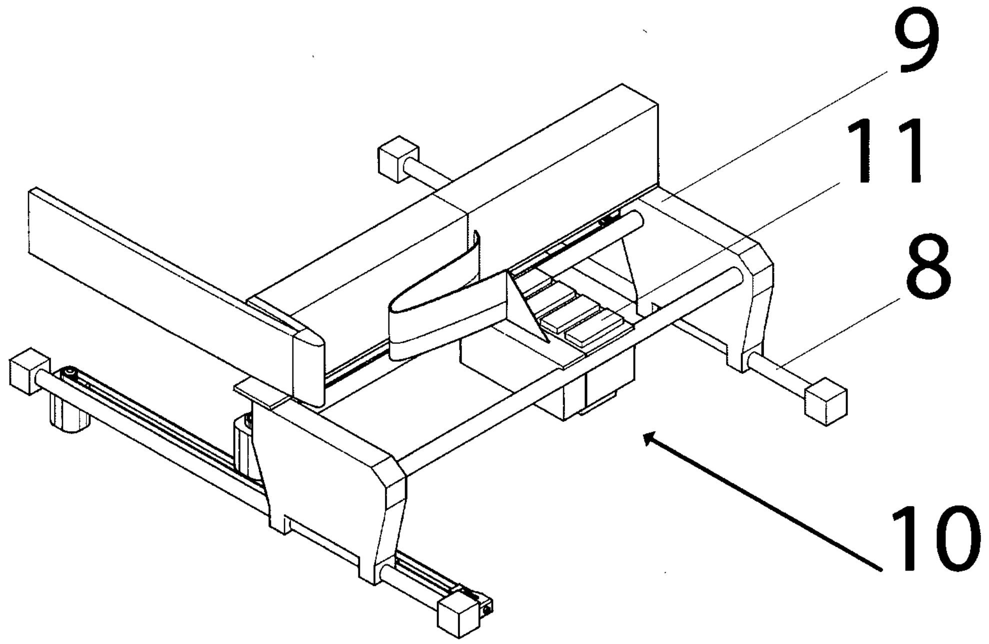

Fig.3

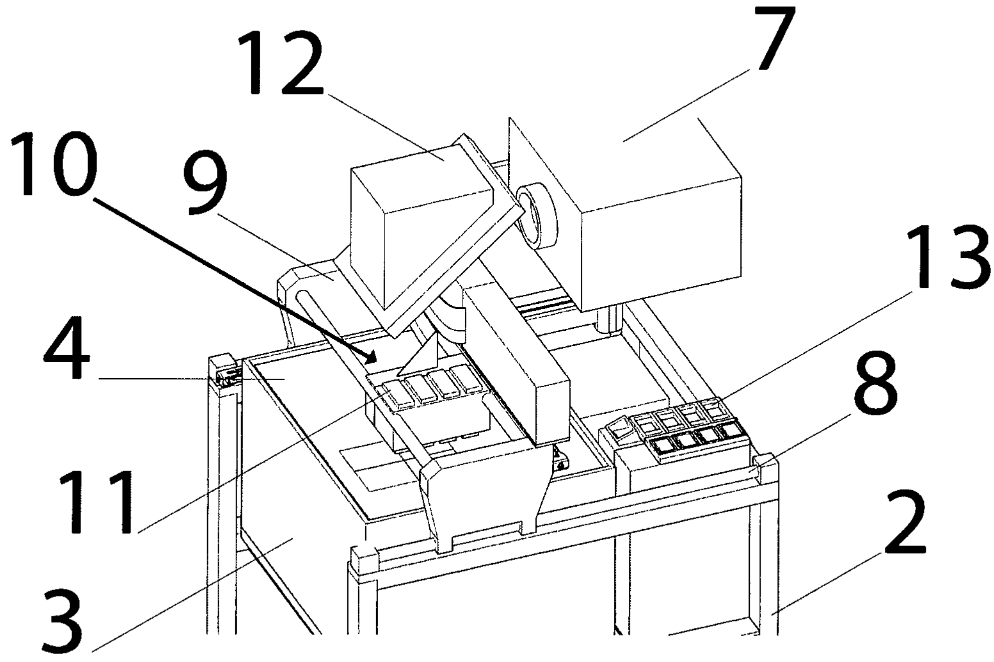

Fig.4

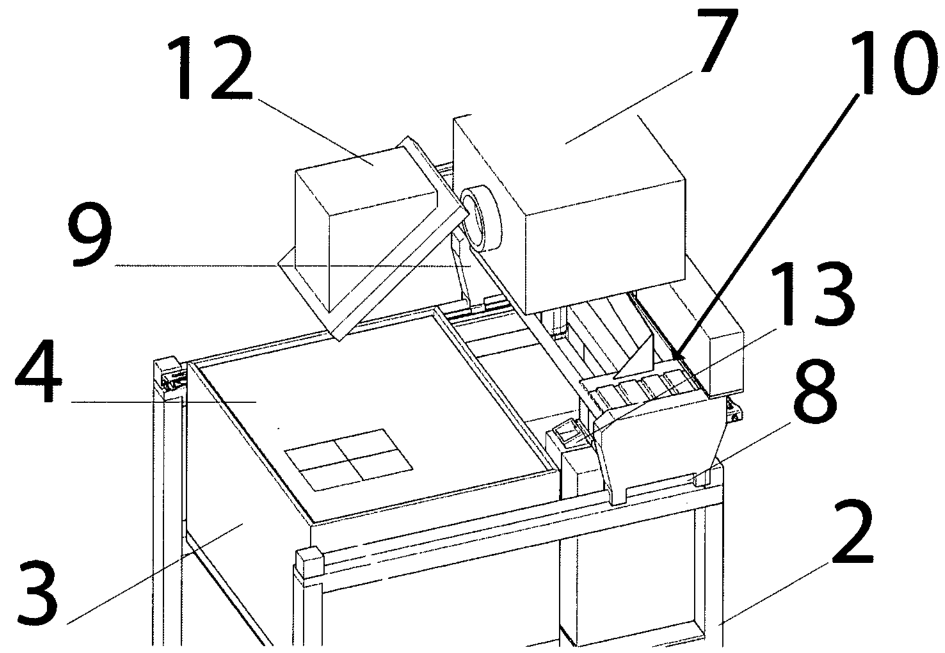

Fig.5

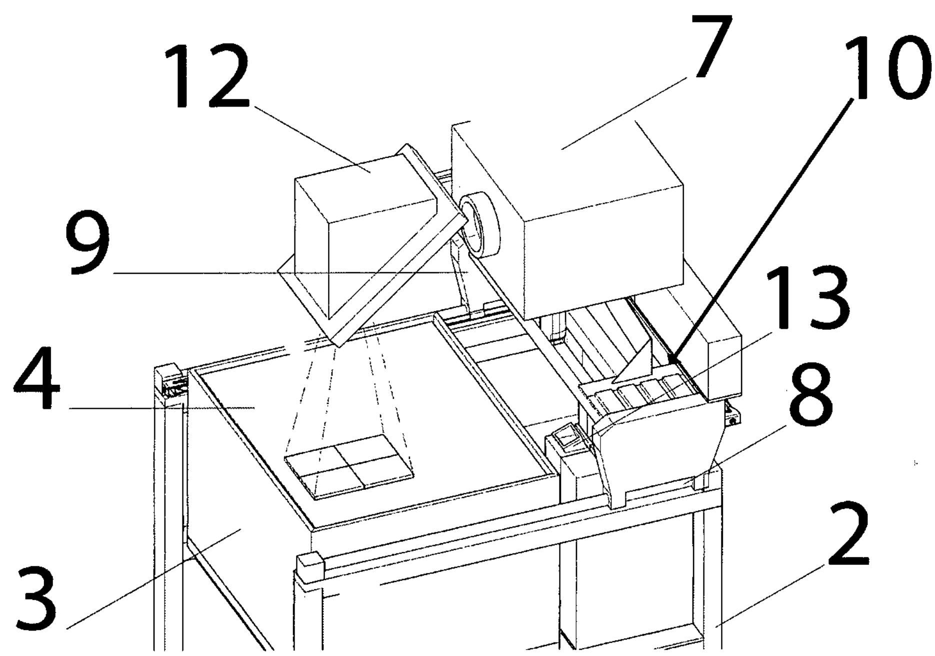

Fig.6

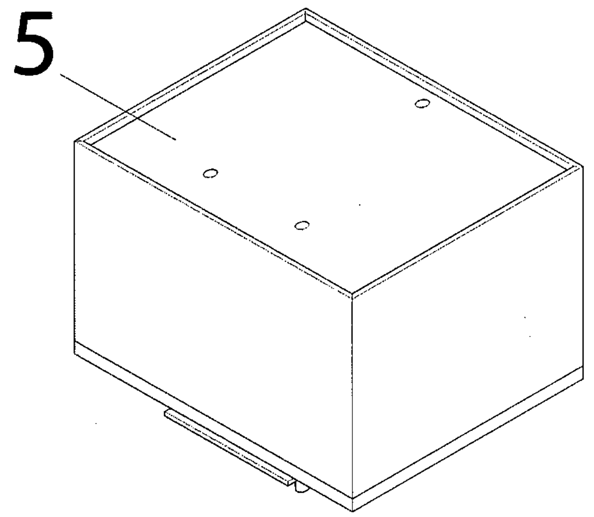

Fig.7

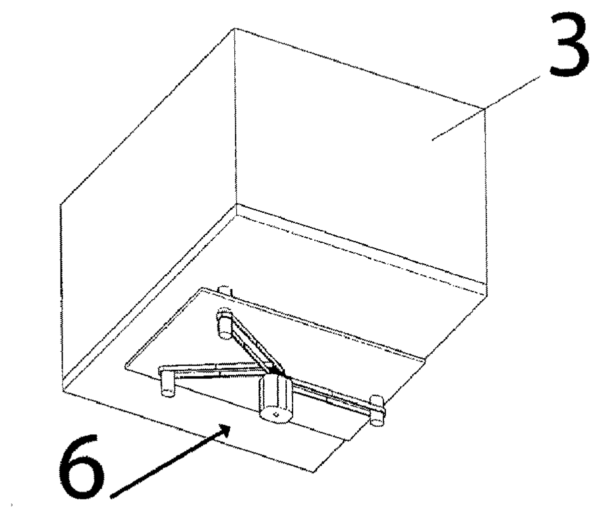

Fig.8

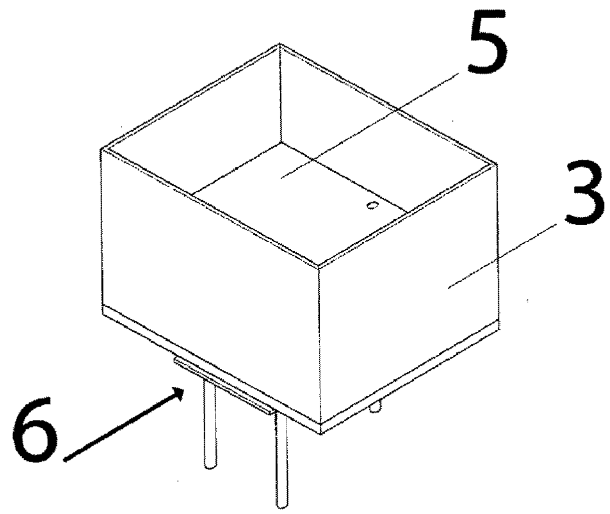

Fig.9

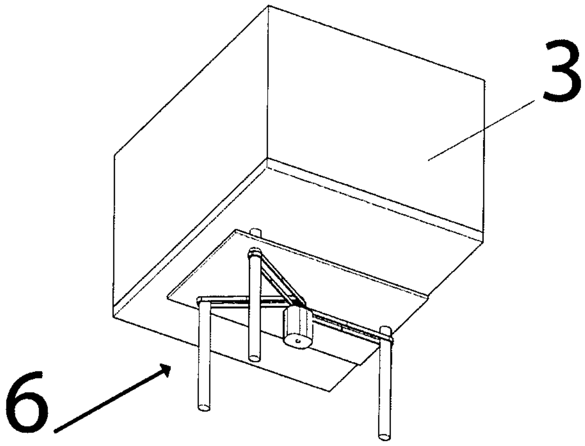

Fig.10

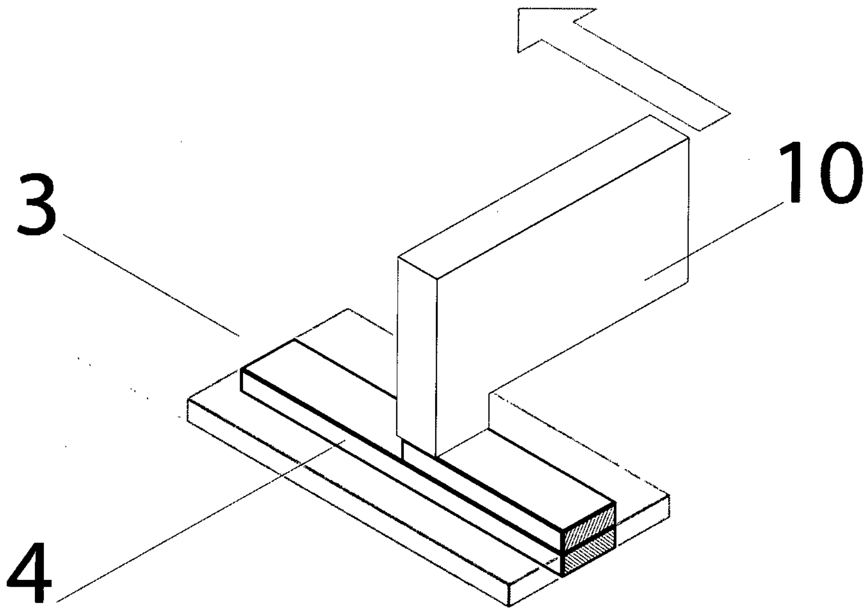

Fig.11

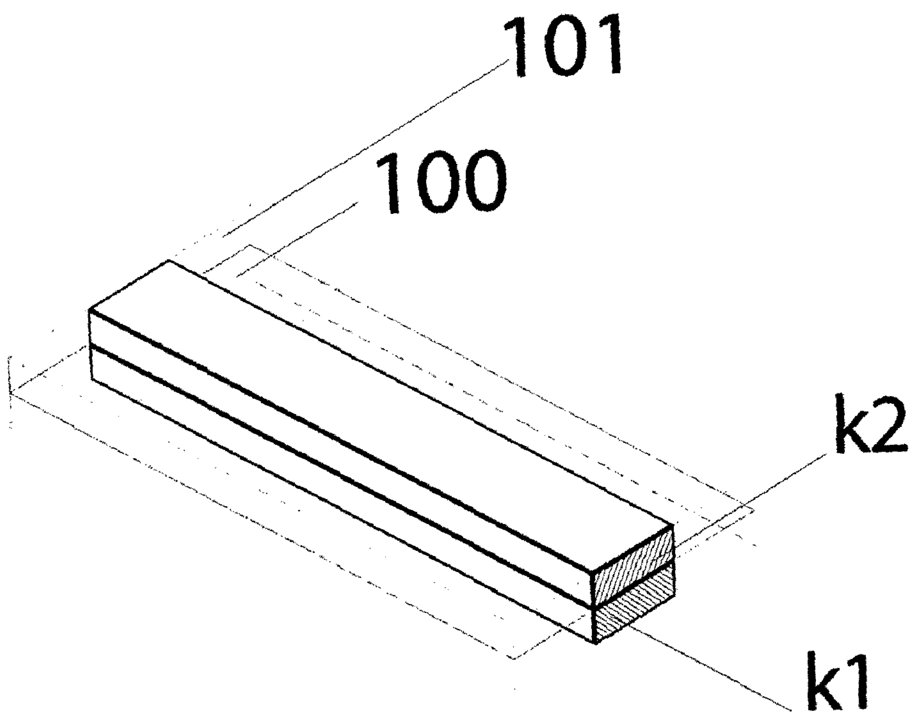

Fig.12

INTERNATIONAL SEARCH REPORT

International application No
PCT/PL2015/000062

A. CLASSIFICATION OF SUBJECT MATTER
INV. B33Y10/00 B33Y30/00 B29C67/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
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	US 2006/225834 A1 (MEDINA FRANCISCO [US] ET AL) 12 October 2006 (2006-10-12)	1,3, 5-12, 14-24
Y	figures 1, 5A-E page 2, paragraph [0009] page 3, paragraphs [0027], [0030] page 4, paragraph [0038] -----	13
X	EP 2 671 706 A1 (IVOCLAR VIVADENT AG [LI]; UNIV WIEN TECH [AT]) 11 December 2013 (2013-12-11) figure 1 page 4, column 6, lines 18-28, 47-50 page 5, paragraph [0031]-[0033] -----	1-3, 5-12,14, 15,20-22

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

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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