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(54) **Title:** METHOD OF TREATING A LAYER OF MATERIAL WITH ENERGETIC RADIATION

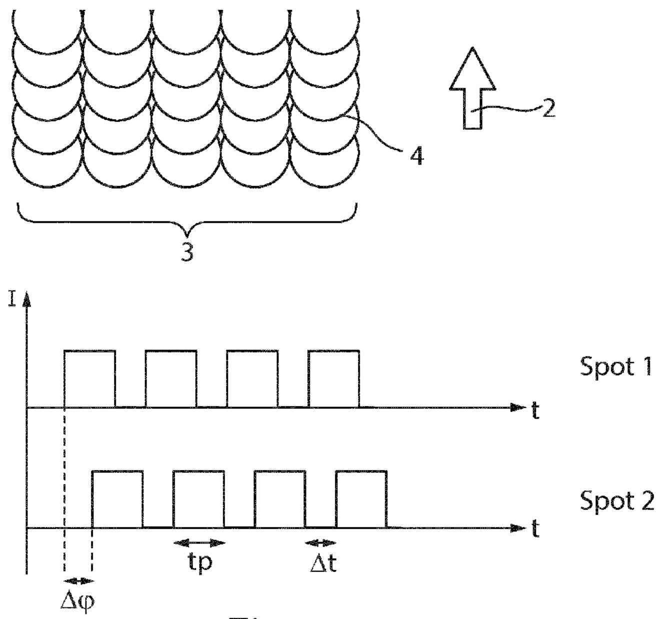

Fig. 2

(57) **Abstract:** In a method of treating a layer of material with energetic radiation, in particular for generative component production, a processing head is used, which is configured to direct separate energetic beams onto the layer of material such that adjacent spots (1) of said separate energetic beams partly overlap at the layer of material. The separate energetic beams are at least temporary directed at the layer of material and are guided in a movement direction (2) over the layer of material. The radiant power of the energetic beams is periodically modulated between a high power for time intervals tp and a low or zero power for time intervals Δt. The periodic modulation of the radiant power is performed such that at least for the outmost regions of said area to be treated within the layer of material, the melting pools forming during the time intervals tp are separated from one another in the movement direction (2). With the proposed method a high surface quality can be achieved and at the same time the advantages of continuous melting pools for influencing the

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SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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form of the melting track are maintained.

Method of treating a layer of material with energetic radiation

Technical Field

The present invention relates to a method of treating a layer of material with energetic radiation, in particular with laser radiation, by means of a processing head which is configured to direct separate energetic beams onto the layer of material such that adjacent spots of said separate energetic beams partly overlap at the layer of material, in which method the separate energetic beams are at least temporary directed to the layer of material and are guided in a movement direction over the layer of material, whereby the layer of material is melted locally within an area to be treated.

With additive or generative manufacturing techniques based on the melting of powder layers with an energetic beam, e.g. the so called selective laser melting (SLM), three dimensional structures can be formed directly based on 3D-CAD models. In a repeating process a thin powder layer of typically less than 100 μm is deposited on a substrate and in the next step selectively fused according to the geometric information from a 3D-CAD model. The energetic beam melts the powder in the selected regions such that the melted material solidifies to form each layer of the structure. With this repeating process three dimensional structures can be formed with only small limitations regarding the constructive complexity. This type of generative manufacturing allows densities of the structure of up to 100% resulting in mechanical properties similar to those achieved with conventional manufacturing processes.

A drawback of such generative manufacturing techniques is the low build rate resulting in a low speed of manufacturing. In order to economically use these techniques in industrial manufacturing, the build rate, i.e. the material volume melted during each time unit, has to be increased. This requires to increase the energy deposition into the powder bed.

Prior Art

US 2016/0114427 A1 discloses a device and method for laser based generative component production allowing an increased build up speed of the three dimensional structures. The device comprises a processing head using which a plurality of mutually separate laser beams are directed adjacently and/or overlapping to some extend onto the processing plane. The processing head is moved across the processing plane using a movement apparatus, while the mutually separate laser beams are modulated independently of one another in terms of intensity, in order to obtain the desired exposure geometry. With the described device and method the laser power and the dimensional size can be scaled cost-effectively during the generative production. Since the melting pool generated with such a device and method is substantially large, dynamic effects in the melting pool like the contraction to ball like structures, limits the resolution of details in the process. Furthermore, in border areas of the component an agglomeration of powder may occur due to the latent heat of fusion released during the solidification, resulting in a poor surface quality of the manufactured components.

In order to overcome the last mentioned problems, the local size of the melting pool is reduced by spatially separating the spots of the spot array in the processing plane. This is described for example in US 2017/0021454 A1. With such a technique however additional degrees of freedom resulting from the usage of a multispot-array cannot be used. Such degrees of freedom include the control of the melting pool dimensions through controlled energy deposition in order to better adapt the solidified melt to the component geometry.

It is an object of the present invention to provide a method of treating a layer of material with energetic radiation, in particular for generative component production, which still provides the above degrees of freedom of larger melting pools without reducing the resolution of details and surface quality of the three dimensional structures or components in generative component production.

Description of the Invention

The object is achieved with the method according to claim 1. Advantageous embodiments of the method are subject matter of the dependent claims or can be drawn from the following description and exemplary embodiments.

In the proposed method of treating the layer of material with energetic radiation, in particular with laser radiation, a processing head is used which is configured to direct separate energetic beams onto the layer of material such that adjacent spots of said separate energetic beams partly (spatially) overlap at the layer of material. The separate energetic beams are at least temporary directed to the layer of material and are guided in a movement direction over the layer of material, whereby the layer of material is melted locally within an area to be treated. The method is characterized in that a radiant power of said energetic beams is periodically modulated between a high power for time intervals tp and a low or zero power for time intervals Δt at least for the outmost of said separate energetic beams directed at the layer of material within the area to be treated, i.e. the beams melting the layer at the border of the area to be treated, the high power being sufficient to melt the layer forming a melting pool, the low power being too low to melt the layer. The periodic modulation of the radiant power is performed such that at least in border areas of the area to be treated, the melting pools formed during the time intervals tp are separated from one another in the movement direction.

With this modulation, the melting pool formed perpendicular and/or parallel to the moving direction by the overlapping adjacent spots may still be continuous in an inner part of the area to be treated -

if required -, but at least at the borders of the area to be treated the melting pools are separated from one another in the movement direction achieving the desired high resolution and surface quality. Due to the possibility of maintenance/conservation of a continuous melt pool in a direction perpendicular to the movement direction or in an inner portion of the area in a direction parallel to the movement direction the above mentioned degrees of freedom are still available. The term continuous melting pool in this context means that the melting pools formed by at least two adjacent spots, i.e. by spots overlapping in a direction perpendicular to the moving direction, or by at least two sequential exposures in the movement direction join forming one single larger melting pool. By appropriately controlling the radiant power of the single energetic spots or energetic beams, in particular the laser power of laser beams, special shapes of the melting tracks can be achieved in order to influence several aspects of the component quality like density, detail resolution or surface quality. It may, for example, be advantageous to modulate the outmost or the outer (including the outmost) energetic beams directed to an outer portion of the area to be treated with a first time interval tp and a first time interval Δt and to modulate the inner energetic beams (directed to an inner portion of the area to be treated) with one or several different time intervals tp and Δt or to operate these inner beams continuously (cw radiation). Dependent on the desired properties of the component to be produced each region of the component can be manufactured with the appropriate properties by correspondingly adapting the modulation and thus the shapes of the melting tracks.

In a preferred embodiment, the periodic modulation of the radiant power is performed such that energetic beams forming adjacent spots at the layer are periodically modulated with a phase shift $\Delta\varphi$ to one another. This phase shift $\Delta\varphi$ of the periodic modulation between energetic beams forming adjacent spots is preferably selected such that the melting pools formed during the time intervals tp on preferably straight lines perpendicular to the moving direction are separated from one another on said lines perpendicular to the moving direction.

The periodic modulation of the radiant power can also be performed such that the melting pools formed during the time intervals tp are separated from one another in the movement direction for all of said separate energetic beams directed at the layer of material within the to be treated area. If only the melting pools formed by the outmost of the separate energetic beams or if the melting pools of all of the separate energetic beams directed at the layer of material within the to be treated area are separated from one another in the movement direction depends on the desired effect or properties of the component in the corresponding area.

The suggested method can principally be used in the field of powder-bed-based generative production methods, for example for selective laser melting or laser sintering. Examples of use in particular include the production of metal, ceramic of polymer components for aviation, automotive and energy industry and also medical technology and tool making.

Brief Description of the Drawings

The proposed method is explained once more in the following on the basis of exemplary embodiments in connection with the drawings. In the drawings:

Fig. 1 shows a schematic illustration of an exemplary spot array of adjacent overlapping spots according to the proposed method;

Fig. 2 shows a schematic view of the solidified melting track achieved according to a first embodiment of the proposed method;

Fig. 3 shows a schematic view of the solidified melting track achieved according to a second embodiment of the proposed method;

Fig. 4 shows a schematic view of the solidified melting track achieved according to a third embodiment of the proposed method;

Fig. 5 shows a schematic view of the solidified melting track achieved according to a fourth embodiment of the proposed method; and

Fig. 6 shows a schematic view of processing phases for manufacturing a three-dimensional component using the proposed method.

Exemplary Embodiments of the Invention

In the proposed method separate energetic laser beams are at least temporary directed to a to be melted layer of powder material such that adjacent spots of said separate energetic beams at least partly overlap at the layer of material, and are guided in a movement direction over the layer of material, whereby the layer of material is melted locally within an area to be treated.

In the following embodiments separate laser beams are used for locally melting the material. Fig. 1 schematically illustrates an arrangement of five laser spots on a processing plane according to the proposed method. The partially overlapping laser spots 1 are arranged in this example in a straight line perpendicular to the movement direction 2 in which this spot array is moved over the layer of material to be locally melted. Such an array of laser spots 1 can be generated, for example, with a device and processing head as disclosed in US 2016/0114427 A1. It is also possible to arrange more than five laser spots in a line, to slightly displace adjacent laser spots in the movement direction 2 or to use a two dimensional array of laser spots 1.

The radiant power of the individual laser beams is periodically modulated during movement in the movement direction 2 between a high power for time intervals tp and a low or zero power for time intervals Δt in order to influence the formation of the melting pool or melting track. In the following, four types of melting tracks are shown, which can be realized with the proposed method by different periodic modulation of the radiant power of the individual laser beams. In these examples or embodiments a spot array with five spots adjacent to each other has been used as shown in Fig. 1.

Fig. 2 shows in the upper part a schematic view on a melting track 3 (part of a melting track) which is generated when moving the above mentioned spot array in the moving direction 2 about a layer of powder material to be fused together. In this embodiment the parameters for the periodic modulation of the single laser beams forming the laser spots are selected such that the circular solidified melting pools overlapping each other are generated as shown in Fig. 2. Such a melting track is achieved by activating the single laser beams repeatedly only for a short time tp while maintaining a phase shift between adjacent laser spots. On the lower part of Fig. 2 the periodic modulation of two adjacent spots (Spot 1 and Spot 2) is illustrated. Each spot is activated for a time tp with a corresponding time interval Δt of zero power between the single activations or pulses. The pulses of the second spot are phase shifted by a phase shift Δφ with respect to the pulses of the first spot. The time periods tp and Δt as well as the phase shift Δφ are selected such that the desired result is achieved. In the present example a relation between Δt and tp of approximately 3 is selected (Δt > tp) whereas the phase shift $\Delta\varphi$ is selected to be approximately tp/2. Typically the time period tp is in the range of some tenths of ms up to < 10 ms, for example between 0.5 ms and 5 ms.

In the example of Fig. 2 the circular solidified melting pools 4 overlap to an extent of < 60%. The separation of individual melting pools parallel and perpendicular to the moving direction can be recognized from the figure. With such a melting track the surface roughness is decreased, in particular at angled side surfaces with respect to a continuous melting pool. Furthermore, the powder adhesion at the borders of the melting track is also decreased and the dimensional accuracy of fabricating components using such a melting track is increased in comparison to the generation of continuous melting pool.

Fig. 3 shows an embodiment in which the pulse length tp (activation time of laser beams) is not changed with respect to the embodiment of Fig. 2, but the phase shift $\Delta\varphi$ between adjacent spots has been removed. The corresponding form of the melting track is different to that of Fig. 2 as can be clearly recognized in Fig. 3. These parameters result in a lamellar solidified structure 5 with an overlap in the movement direction of < 60%. The melting pools (solidified melting pools 5) are separated parallel to but interconnected perpendicular to the moving direction 2. This means that a continuous melting pool is achieved in the direction perpendicular to the moving direction 2 but separated in the direction parallel to the moving direction 2. With such modulation parameters a higher density of the manufactured component and also a further improved surface quality on the top side of the component is achieved compared to a melting track form as that of Fig. 2.

By increasing the pulse length (activation length tp) of the single beams the corresponding melting pool is increased in the movement direction 2 resulting in a melting track as exemplary shown in Fig. 4. The pulse length tp has been increased in this example by a factor of 10 with respect to the pulse length of the examples of Figs. 2 and 3. The distance between the single pulses Δt has been selected such that the relation between Δt and tp is approximately 0.5 ($\Delta t < tp$). In Fig. 4, no phase shift $\Delta\varphi$ between adjacent pulses has been applied. Such parameters lead to a kidney shaped solidified structure 6. The melting track results in identical component densities as can be achieved with a continuous wave (cw) process, i.e. with continuous laser radiation. On the other hand the surface quality at the top layers of the component is significantly enhanced with respect to a cw process. Also the roughness at angled side surfaces is decreased with respect to a cw process.

Adding a phase shift $\Delta\varphi$ as already described in connection with Fig. 2, the single melting track segments begin to connect in the middle of the track while remaining separate in the moving direction at the boarders of the track. In Fig. 5, the phase shift $\Delta\varphi$

between every two adjacent pulses has been selected to be $(tp+\Delta t)/2$, resulting in the schematically shown melting track 3. Such parameters lead to a ψ-shaped solidified melting pool/structure 7 with an overlap of < 60%. The corresponding parameters lead to an increased melt size compared to the lamellar structure of Fig. 3. Such a selection of parameters results in a decreased surface roughness at top surfaces, a decreased roughness of angled side surfaces and a high density of the manufactured component. Additionally to the embodiment of Fig. 3 also the detail resolution is improved with such parameters.

The examples of Figs. 2 to 5 show that the properties of the component to be manufactured can be influenced by a variation of the melting track form. Preferably, during the preparation of any manufacturing process of three dimensional components the requirements or properties of the to be manufactured components are considered and the control of the laser spots during manufacturing are then performed in order to adapt the melting track to the desired properties of the component. An adaption of the form of the melting track can be achieved within a very short time scale of a few ten microseconds during exposure, for example between 50 and 200 μs. Fig. 6 shows a schematic view of such a performance. In a first processing phase 8 the properties of the component to be manufactured are assigned to specific part areas. In the second processing phase 9 the appropriate melting track shapes matching the required properties are selected and in the final processing phase 10 the laser control is adapted on the fly to achieve the required shapes in the corresponding areas.

List of Reference Signs

1	Laser spot
2	Movement direction
3	Melting track
4	Circular solidified melting pool/structure
5	Lamellar solidified melting pool/structure
6	Kidney shaped solidified melting pool/structure
7	ψ-shaped solidified melting pool/structure
8	Assignment of properties
9	Selection of melting track shapes
10	Adaptation of laser control

Patent Claims

1. A method of treating a layer of material with energetic radiation, in particular with laser radiation, by means of a processing head, which is configured to direct separate energetic beams onto the layer of material such that adjacent spots (1) of said separate energetic beams partly overlap at the layer of material,
in which method the separate energetic beams are at least temporary directed to the layer of material and are guided in a movement direction (2) over the layer of material, whereby the layer of material is melted locally within an area to be treated,
characterized in that
a radiant power of said energetic beams is periodically modulated between a high power for time intervals tp and a low or zero power for time intervals Δt at least for outmost regions of said area to be treated, the high power being sufficient to melt the layer forming a melting pool, the low power being too low to melt the layer,
the periodic modulation of the radiant power being performed such that at least for the outmost regions of said area to be treated, the melting pools formed during the time intervals tp are separated from one another in the movement direction (2).

2. The method according to claim 1,
characterized in that the periodic modulation of

the radiant power is performed for all of said separate energetic beams directed at the layer of material within the area to be treated.

3. The method according to claim 2, characterized in that the periodic modulation of the radiant power is performed such that energetic beams forming adjacent spots (1) at the layer are periodically modulated with a phase shift $\Delta\varphi$ to one another.

4. The method according to claim 3, characterized in that the phase shift $\Delta\varphi$ is selected to be $(tp+\Delta t)/2$.

5. The method according to one of claims 2 to 4, characterized in that the periodic modulation of the radiant power is performed such that the melting pools formed during the time intervals tp are separated from one another in the movement direction (2) and perpendicular to the movement direction (2).

6. The method according to claim 1 or 2, characterized in that the periodic modulation of the radiant power is performed such that a continuous melting pool is formed perpendicular to the moving direction (2).

7. The method according to claim 6, characterized in that the periodic modulation of the radiant power is performed such that the melting pools formed during the time intervals tp

are separated from one another in the movement direction (2).

8. The method according to one of claims 1 to 6, characterized in that the periodic modulation of the radiant power is performed such that one or several continuous melting pools are formed parallel to the moving direction (2) in an inner region of the area to be treated.

9. The method according to one of claims 1 to 8, characterized in that the time intervals tp and time intervals Δt selected for the outmost of said separate energetic beams directed at the layer of material within the area to be treated are different from the time intervals tp and time intervals Δt selected for at least some of the energetic beams directed at an inner part of the area to be treated.

10. The method according to one of claims 1 to 9, characterized in that the time intervals tp and time intervals Δt are selected to be between 0.05 ms and <10 ms.

11. The method according to one of claims 1 to 10 for generative component production.

12. A component built up by generative component production layer by layer using the method of one or several of the preceding claims for forming the individual layers.

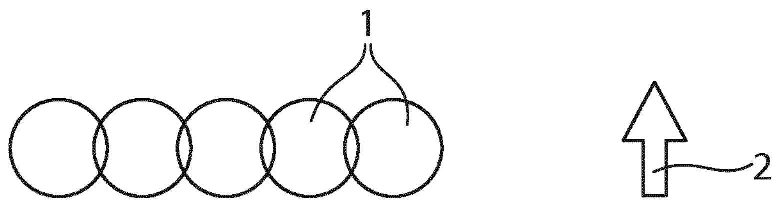

Fig. 1

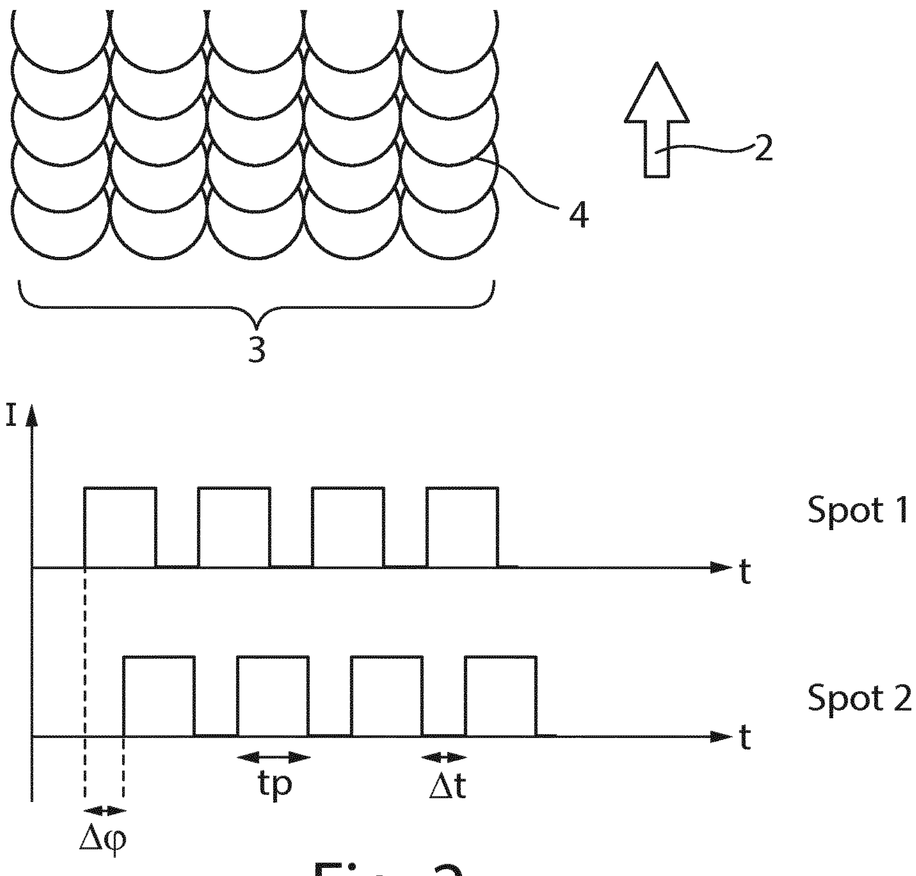

Fig. 2

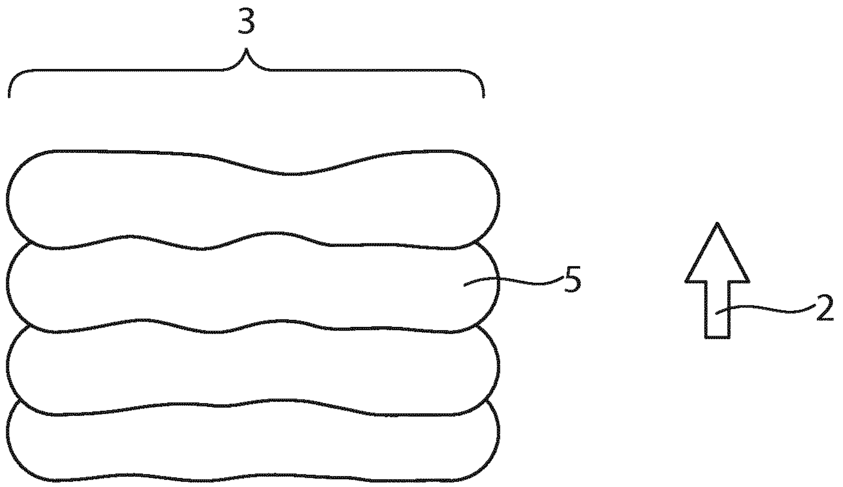

Fig. 3

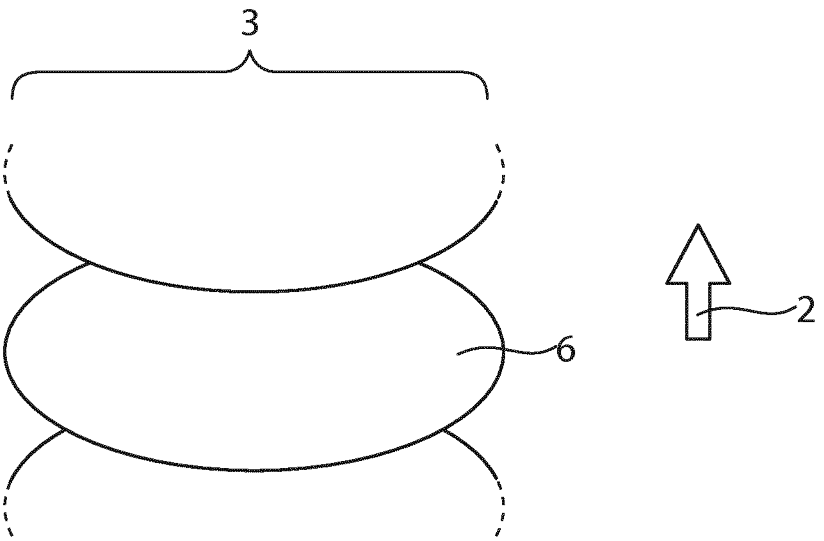

Fig. 4

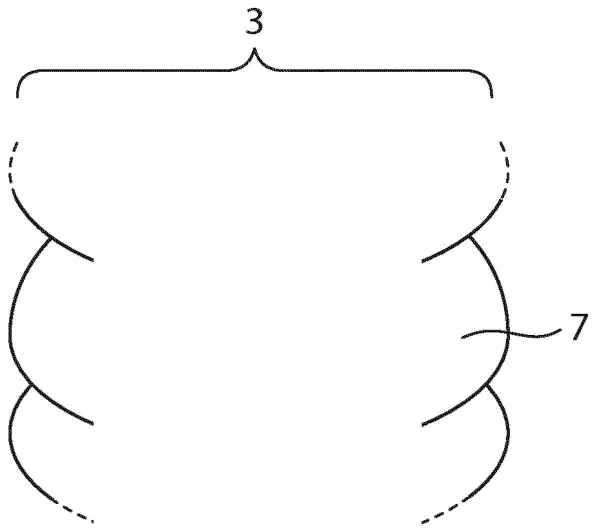

Fig. 5

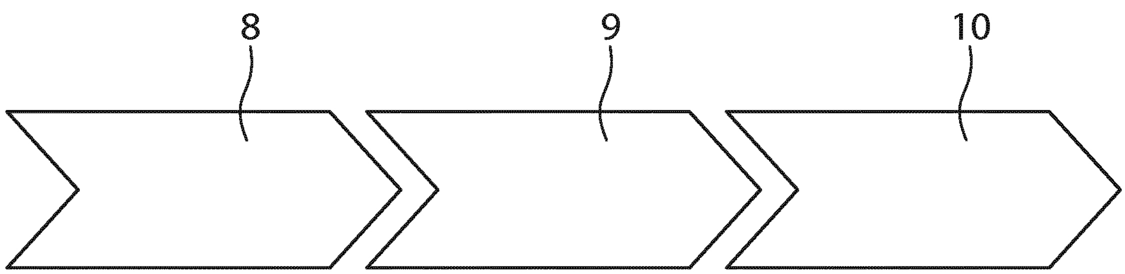

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/086895

A. CLASSIFICATION OF SUBJECT MATTER
INV. B22F3/105 B33Y10/00 B33Y50/02 B29C64/153 B29C64/393
B29C64/273 B29C64/282
ADD. B23K26/06

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 B23K B33Y B29C A61C

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

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Y	paragraphs [0001] - [0006], [0016] - [0017], [0030], [0035]; figures 1,5-6,8	1-11
	paragraphs [0014], [0021], [0041], [0051]; figures 9-14	

X	US 2018/201028 A1 (DEPPE CARSTEN [DE]) 19 July 2018 (2018-07-19)	12
Y	abstract; claims 1-2,8-9; figures 3,4,12-13	1-11
	paragraphs [0002], [0007] - [0009], [0013], [0064]	
	paragraphs [0030], [0072] - [0077]	

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

[X] See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
22 August 2019	29/08/2019

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Aliouane, Nadir

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	ZAVALA-ARREDONDO MIGUEL ET AL: "Laser diode area melting for high speed additive manufacturing of metallic components", MATERIALS & DESIGN, ELSEVIER, AMSTERDAM, NL, vol. 117, 3 January 2017 (2017-01-03), pages 305-315, XP029896145, ISSN: 0264-1275, DOI: 10.1016/J.MATDES.2016.12.095	12
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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