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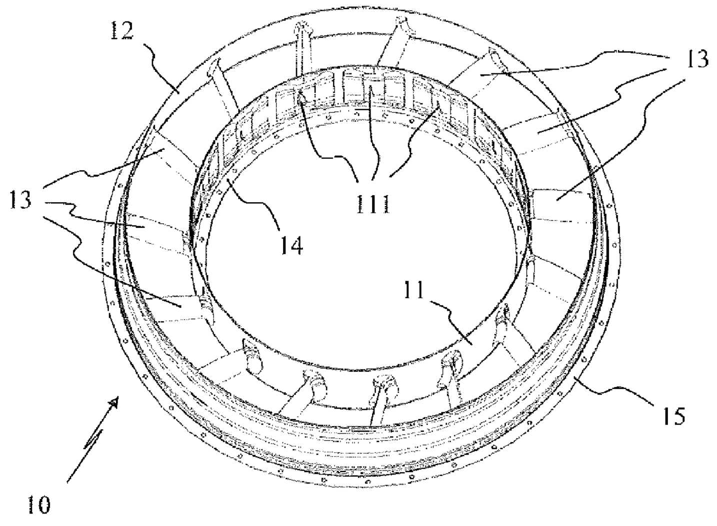

Fig. 1

(57) **Abstract:** A process for the production of a monolithic metal component for turbine engines, by means of a technique of the "additive manufacturing" type, is described. The component has a substantially cylindrical shape and is obtained in a laser beam powder-bed fusion apparatus. The process provides a preventive simulation step of the building of the component and a monitoring step in situ for each last melted layer.

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"PROCESS FOR THE SERIAL PRODUCTION OF STRUCTURAL MONOLITHIC METAL COMPONENTS FOR TURBINE ENGINES"

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Technical Field of the Invention

The present invention concerns a process for the production of a monolithic metal component of a substantially cylindrical shape and, in particular, a process for the production of components of a turbine engine in the field of the aeronautical industry.

Turbine engines comprise various components that operate under fatigue since subjected to high operating temperatures, for example between 700°C and 800°C during the various steps of take-off and cruising at aircraft cruising speed.

In particular, components with a substantially cylindrical shape are present at the end of turbine engines, such as the so-called "Turbine Rear Vane" (hereinafter TRV) and possibly also the so-called "Turbine Rear Frame" (hereinafter TRF), the latter being in turbine engines composed of more than five stages. These components are large components with a particularly complex geometry.

The TRV component includes two rings or concentric cylindrical belts joined to each other by equidistant blades. For example, the inner cylindrical ring can have a maximum diameter of about 400 mm, while the outer cylindrical ring, or the relative flange, can have a maximum diameter of about 1600 mm. The blades joining them have profiles that are suitably shaped for guiding the flow of gas coming out from the turbine engine, are angled with respect to the radial direction and are preferably made with a cavity inside them so that to limit the overall weight of the component. Both of the cylindrical rings also have a circumferential flange to allow the fastening of the component to the rest of the turbine engine.

The TRF component can also have a complex geometry and is formed by a main body substantially in the shape of a cylindrical ring with blades arranged inside and outside of the main body. The maximum diameter of this component, including the outer blades, can reach about 1600 mm.

Since these components are subjected to high temperatures, the materials with which they are made are generally nickel-based alloys, such as for example the so-called "superalloys" identified by the trade names RENE' 220, HAYNES 282, INCONEL 718 and RS5. It is however difficult to process these materials with the normal precision casting techniques.

Prior art

The TRV and TRF components are currently made by casting, at least in most cases. As a result of the considerable dimensions of these components, their complex geometries and the difficulties in processing the materials used, it is practically impossible to make these components in a monolithic form while simultaneously ensuring the necessary reliability.

Some studies related to the possibility of making monolithic components with these types of materials were documented in literature, such as for example in the work of M.L. Gambone, S.B. Shendye, P. Andrews, W. Chen, M.N. Gungor, J.J. Valencia e M.L. Tims ("*Properties of RS5 and other superalloys cast using thermally controlled solidification*", pp. 161-170, Superalloys 2000, Edited by T.M. Pollock, R.D. Kissinger, R.R. Bowman, K.A. Green, M. McLean, S. Olson, and J.J. Schirra - TMS The Minerals, Metals & Materials Society, 2000). A dimensional increase of cracks was detected at temperatures above 650°C in the samples obtained by casting.

As a result of their large dimensions, the TRV and TRF components are currently made by casting in more parts which are then welded together so that to form the final component. A study of the effects of welding for making a TRV component in more parts welded to each other was presented for example by F. Pichot and N. Poletz ("*Welding simulation of aircrat engine large components*" - Conference Paper · September 2015).

In practice, "wedges," comprising a portion of the inner circumferential ring, a portion of the outer circumferential ring and a certain number of blades joined to the two portions of circumferential rings, are first obtained to form the TRV component. The wedges are then welded to each other to complete the component and, in some cases, the circumferential flanges are also made separately and then welded to the respective cylindrical rings.

The parts obtained by casting are generally subject to warpage and must therefore be straightened before being welded to each other. It may not be possible to straighten the part obtained by casting, so that to combine it to the other parts, in case of excessive warpage and it must therefore be rejected. In fact, it is appropriate to keep in mind that the processing tolerances to be respected for a TRV component are very narrow, in the order of tenths of a millimeter, and therefore require long processing times for obtaining a reliable final product. For these reasons, it is necessary to provide for the casting of parts with excess metal, especially as far as the flanges are concerned, which will then be removed by mechanical removal so that to achieve the desired accuracy.

Experts of the field well know that each welding is a potential zone of breakage. The TRV component has a bearing function since it supports the supporting components of the shaft of the turbine in the back part of the engine. Therefore, in addition to being subjected to high temperatures, it must withstand the mechanical stresses of the turbine which can cause breakage at the weldings.

Moreover, as a result of the scarce fluidity which the nickel alloys mentioned manifest at the melting state during the casting of the single parts, it becomes very difficult to obtain the cavities in the blades. Firstly, the cavities of the blades in the parts obtained by casting must necessarily be open; the openings of the cavities, which are created in the blades on the outer surface of the outer cylindrical ring, must be reclosed by welding small metal patches (also known as "gussets"), therefore adding further weldings which, in addition to requiring long processing times, increase the possibility of breakages also in these zones. Moreover, still as a result of the scarce fluidity of the melted material, the walls of the blades must be sufficiently thick so that to properly form the blades themselves and the respective cavities, and this therefore has negative impact on the overall weight of the TRV component.

Productive techniques, in which at least the cylindrical rings of the TRV component are obtained by calendering metal belts which are then joined at their ends by welding to form each cylindrical ring, are also known. Therefore, the cylindrical rings must be processed to form the openings in which the blades are then inserted; the latter, still obtained separately by casting, must therefore be attached by welding to the cylindrical rings and, in this case, the inner cavities of these blades must also be reclosed on the outer cylindrical ring by welding the so-called "gussets".

In short, it is clear that the production of the TRV component with the currently known techniques requires long processing times and costs, involving high production wastes, and the final product can be subject to breakage over time due to the severe operating conditions.

The same considerations are also valid for the TRF component which, although having a less complex geometry with respect to the TRV component, anyhow has large dimensions and must therefore necessarily be made in more parts obtained by casting which are then welded to each other so that to form the final component.

Summary of the Invention

Object of the present invention is therefore to propose a process for the production of a metal component for turbine engines which has a monolithic structure, including the flanges or other equivalent fastening means, so that to avoid the welding of parts prepared separately.

A further object of the present invention is to propose a process of the aforesaid type, which allows to considerably limit the production times and costs of the monolithic component.

A further object of the present invention is to propose a process of the aforesaid type, which allows to limit the weight of the final monolithic component, by making hollow structures with thin walls.

Still a further object of the present invention is to propose a process of the aforesaid type, which allows to considerably limit the production wastes.

Still a further object of the present invention is to propose a process of the aforesaid type which allows to eliminate, or anyhow considerably limit, the formation of cracks in the structure of the monolithic component, so that to result more reliable with respect to the components obtained with the processes of the known type.

A further object of the present invention is to propose a process of the aforesaid type, which allows to produce monolithic components for turbine engines also with difficult to melt or weld metal materials.

Still a further object of the present invention is to propose a process of the aforesaid type which allows to also produce, reliably and with precision, monolithic components of large dimensions.

These objects are achieved by the present invention thanks to a process according to claim 1. Further peculiar characteristics of the process are set forth in the respective dependent claims.

In general, a process for the production of a monolithic metal component for turbine engines is provided. The component is essentially cylindrical in shape and is obtained in a laser beam powder-bed fusion apparatus comprising a fusion chamber housing a mobile build plate movable at least along a direction parallel to the axis of the monolithic component to be produced, and at least one mobile powder distributor. The process comprises the steps of:

a) generating a three-dimensional mathematic model of the component;

b) storing the three-dimensional mathematic model of the component in a control unit of the apparatus;

c) preparing the powders of the metal material to be used;

d) depositing a quantity of powders in the fusion chamber of the apparatus to form a layer of powders with a regular and substantially uniform thickness;

e) heating and maintaining the fusion chamber of the apparatus at a temperature below the fusion temperature of the powders;

f) melting, by means of laser beams, the layer of powders deposited during step d) by scanning the area corresponding to a layer of the component, according to the three-dimensional model stored in the control unit of the fusion apparatus;

g) injecting a flow of inert gas at the layer of the component just melted in step f);

h) repeating the steps from d) to g) until reaching the last layer of the component according to the three-dimensional model stored in the control unit.

The powders are deposited in step d) with a rotary motion around the axis of the component and the laser beams are oriented in step f) on the powder layer just deposited in step d).

According to the invention, the process provides in particular the steps of:

- simulating the building of the component between the steps a) and b); and
- monitoring in situ each last melted layer after step g) before repeating the steps from d) to g).

The preventive simulation of the building of the component is carried out in a processor suitably programmed to verify the correctness of the structure of the component in general and, in particular, to compensate possible distortions and to optimize the building supports.

Moreover, the monitoring in situ of the layers that are formed during the building steps allows to see, for example, the temperatures of the component being formed by means of heat analyses. For example, analyses of the "melt pool" type can be used in a continuous and efficient way to monitor and store each layer deposited to form the component.

This way, it is possible to produce a monolithic component of large dimensions and a complex geometry in a continuous way, making the powders just deposited melt by means of laser beams which immediately follow the deposition of the powders. The production times are drastically reduced with respect to the known art, since the final product is a component which does not require the welding of parts produced separately.

Advantageously, the component for turbine engines obtained with the process according to the invention is a component which also includes the flanges, or similar fastening element, made in one piece with the rest of the component.

Moreover, with respect to the processes in which the parts of the component are obtained by die-casting or melting in a mold, the process in the fusion chamber occurs at low temperatures, therefore avoiding the formation of cracks and limiting the warpage of the final product. In fact, the fusion chamber is heated in step d) and maintained, throughout the entire process, at a temperature not exceeding 200°C, i.e. at a much lower temperature than the melting temperatures of the nickel alloys used.

According to the present invention, the programming of at least of the power of the laser beams and at least of the scanning speed of the beams is provided before carrying out step f).

The alloys are selected among the ones known under the trade names RENE' 220, HAYNES 282, INCONEL 718 and RS5, which generally have melting temperatures between 1200 and 1400 °C, i.e. temperatures that are found during the process of the present invention only in the points in which the incident laser beams cause the melting of the material.

According to an aspect of the process, the flow of inert gas is injected in step g) along a radial direction moving away from the axis of the component. This way, the possible condensation, forming in the melting zone and which could mitigate the laser beams acting on the zones close to the one in which the fusion was carried out, is evacuated. For example, argon or nitrogen injected at low pressure in the radial direction towards the melting zone can be used.

The powders prepared in step c) are preferably stored in protective atmosphere, for example in inert gas atmosphere, before being loaded in the apparatus. Once loaded, the powders, in step d), can preferably be deposited by making the mobile powder distributor rotate around the axis of the component, or by making the mobile build plate rotate around the axis of the component, or anyhow with a relative rotary motion between the mobile powder distributor and the mobile build plate.

The powders of metal material can have a particle size ranging between 10 and 150 μm and can be obtained by means of gas atomization or plasma atomization processes. The component obtained with the process of the present invention only requires finishing treatments, for example mechanical flattening treatments, of hole recovery in the flanges and a polishing treatment to reduce the roughness index of the outer surfaces to the design values.

Moreover, as far as the TRV component is concerned, the walls of the cavities can be obtained with more reduced thicknesses with respect to the known art and the surfaces of the cavities inside the blades can already have an acceptable roughness index, therefore not requiring further processing.

In the process according to the invention, the powders substantially have the same chemical composition of the material with which the component is made, therefore making the production of components with the same characteristics repeatable.

At the end of the building process, the component remains attached to the build plate. The component and the build plate are therefore extracted together from the apparatus and transferred in a vacuum furnace to perform a stress relieving heat treatment so that to reduce the inner stresses of the component without altering its hardness.

Subsequently, the component is separated from the build plate, preferably by wire cutting in an electrical discharge machine suitably sized according to the maximum dimensions of the component. A machine of this type can be, for example, a model of the AgieCharmilles CUT series, produced by GF Machining Solutions, adapted to host a plate and component set in a cubic volume of 1610 mm for each side. The build plate can be reintroduced and reused in the fusion apparatus.

Once separated from the build plate, the component is therefore subjected to a solubilization and aging heat treatment in a vacuum furnace so that to fix the desired microstructure of the component, i.e. the microstructure which maximizes the fatigue resistance of the component; each flange is therefore processed in a milling machine.

Brief Description of the Drawings

Further advantages and characteristics of the present invention will become clear in the following description, made with reference to the schematic drawings attached by way of example and without limitations, in which:

- Figure 1 is a perspective view of a monolithic TRV component made according to the process of the present invention;
- Figure 2 is a perspective view of a monolithic TRF component made according to the process of the present invention;
- Figure 3 is an axial sectional view of a monolithic TRV component being produced according to the process of the present invention;
- Figure 4 is a top plan view of the monolithic TRV component of Figure 3; and
- Figure 5 is a perspective and cross-sectional view of a particular of the monolithic TRV component of Figure 1.

Detailed Description

A monolithic TRV component 10, made according to the process of the present invention, is shown in Figure 1. The TRV component 10 has substantially cylindrical shape and is formed by an inner cylindrical ring 11 and an outer cylindrical ring 12 joined to each other by a plurality of equidistant blades 13.

The cylindrical rings 11 and 12 are concentric and are both provided with fastening flanges with holes. In particular, the inner cylindrical ring 11 has a circumferential flange 14 which is jutting out towards the inside of the TRV component 10 and the outer cylindrical ring 12 has a circumferential flange 15 which is jutting out towards the outside of the TRV component 10.

A possible embodiment of a TRF component 20, which can also have a more complex geometry than the one represented herein by way of example, is shown in Figure 2. The TRF component 20 is a component of a substantially cylindrical shape and is formed by a cylindrical ring 21 with blades 22 which are jutting out inside the cylindrical ring 21 and blades 23 which are jutting out outside of the cylindrical ring 21.

Before beginning the building process in a laser beam powder-bed apparatus suitably sized to allow the production of a monolithic component 10 (or 20 in case of a TRF) of large dimensions, a simulation of the building of the component 10 is carried out in a suitably programmed computer. In particular, this allows to compensate possible distortions by making, for example, slight modifications to the mathematic model, and to optimize the building supports of the layers which are subsequently formed. The building supports are generally constituted by thin, or less dense, structures which are simultaneously made with the component 10 and therefore removed at the end of the formation of the component itself.

The powders of the metal material to be used are prepared by using, for example, gas or plasma discharge atomization techniques, and therefore stored in protective atmosphere before being loaded in the powder-bed fusion apparatus.

An intermediate step of the production process of a TRV component 10 in monolithic form according to the present invention is shown by way of example in Figures 3 and 4.

The component 10, here depicted in a sectional view according to an axial plane, is obtained in a laser beam powder-bed fusion apparatus which comprises a fusion chamber housing a mobile build plate 30 and a mobile powder distributor 40. The fusion apparatus is provided, in a known way, with an irradiation device 50 which comprises optical tools able to direct focused laser beams 51 towards the powders deposited by the mobile distributor 40.

The build plate 30 is movable at least along a direction parallel to the axis A of the monolithic component to be produced, a direction that is denoted by the arrow B in Figure 3.

The laser beam powder-bed fusion apparatus is provided with a control unit 55 in which the mathematic model of the component 10 is stored. The control unit 55 is able to manage, for example, at least the movements of the mobile build plate 30, of the powder distributor 40 and of the irradiation device 50. The powders of the metal material to be used are loaded in a continuous way in the powder distributor 40, which deposits them in the fusion chamber with a rotary movement, denoted by the arrow D in Figure 4, around the axis A of the component 10 to be produced. The powders just deposited are immediately melted by laser beams 51 which are oriented by the control unit 55 towards the areas in which the fusion according to the mathematic model of the component 10 is provided.

During the process, the fusion chamber is heated and maintained at a temperature relatively lower than the powder melting one, for example at a temperature not exceeding 200°C. The heating can be obtained in a known way, for example by means of electric resistors controlled by the control unit 55 of the laser beam powder-bed fusion apparatus.

A flow of inert gas, such as for example argon or nitrogen, is injected at low pressure at the L area in which the layer just melted is located, so that to remove possible condensations forming following the melting of the powders from the fusion chamber. The flow of inert gas is preferably oriented in the radial direction, denoted by the arrow G, moving away from the axis A of the component 10.

During the powder melting step of each layer of the component, the monitoring of the melted pool is preferably carried out in situ so that to highlight possible fusion defects.

At the end of the building process, the component 10 (or 20 in case of a TRF) remains attached to the build plate 30. The component and the build plate are therefore extracted together from the apparatus and transferred in a vacuum furnace to perform a stress relieving heat treatment so that to reduce the inner stresses of the component 10.

Subsequently, the component 10 is separated from the build plate 30 by wire cutting in an electrical discharge machine suitably sized according to the maximum dimensions of the component 10. Once separated from the build plate 30, it is therefore subjected to heat treatment, for example a solubilization and aging treatment, in a vacuum furnace to fix the microstructure which maximizes the fatigue resistance of the component. Each flange 14 and/or 15 of the component is therefore processed in a milling machine.

A detail of a wing 13, in which a cavity 113 with an opening 111 at the inner ring 11 is obtained, while it is closed at the outer ring 12, is shown in the sectional view of Figure 5. The process according to the present invention allows to considerably reduce the thickness of the walls of the blade 13 which surround the cavity 113, therefore allowing to reduce the overall weight of the component 10.

In addition to the advantages specifically mentioned up to now, it should be noted that the times necessary for the production of the component with a process according to the present invention are drastically reduced with respect to the known art since the final product has a monolithic structure and does not require weldings. Moreover, this further makes the component itself more reliable and even more resistant to high temperatures.

A further advantage of the additive process of the present invention is to be able to make particular portions of the component, such as for example the hollow blades of the TRV component, with more reduced thicknesses compared to those obtainable by means of the fusion processes, therefore obtaining a lighter component with the same resistance.

Further characteristics of the present invention are hereinafter described with reference to an embodiment example (EXAMPLE 1) of a TRV component according to the present invention and to an exemplary embodiment of the same component (EXAMPLE 2 - example of comparison) by precision casting separate pieces and subsequently welding them.

<u>EXAMPLE 1: Production of a TRV component with laser beam powder-bed fusion</u>

After a simulation step of the building of the TRV component, the optimized mathematic model is loaded in the control unit of the apparatus for constructing a raw TRV component with an outer diameter of 1200 mm and an inner diameter of 600 mm, both measured on the flanges, and height of 250 mm.

Inconel 718™ nickel-based alloy powders, a material with a melting temperature of about 1340 °C, were prepared.

The powders were obtained by means of a plasma atomization process and had a particle granulometric distribution ranging between 10-63 μm.

After storing in protective atmosphere, the powders were loaded in the mobile powder distributor located inside the fusion chamber of a laser beam powder-bed fusion apparatus able to emit, for example, from six to eight laser beams with a maximum power of 1 kW each. The rotation speed of the mobile powder distributor was set to deposit a layer of powders with a thickness of about 70 μm.

The apparatus was programmed to emit laser beams at the power of about 800 W at a scanning speed of 1000 mm/sec.

The heating temperature of the fusion chamber was set and maintained at about 80°C.

The production process required about 70 hours to achieve the entire TRV component, including the flanges, at the raw state. The roughness of the outer surfaces had an index of about 14 RA, therefore requiring a polishing treatment of the outer surfaces to reduce the roughness index to the value desired for the outer surfaces (RA lower than 3.2), while the roughness of the inner surfaces of the cavities in the blades satisfied the design requirements.

The TRV component and the build plate to which it remained attached were subjected to a stress-relieving heat treatment in a vacuum furnace for about 10 hours. After cooling, the TRV component was separated from the build plate in a wire-cutting electrical discharge machine and was once again subjected to a solubilization and aging heat treatment, always in a vacuum furnace, for the duration of about 40 hours.

After the mechanical processes for removing the supports, for milling the flanges and for recovering the holes present therein, the final component had an overall weight of about 70 kg, with the walls of the cavities of the blades with a thickness of about 1.2 mm.

<u>EXAMPLE 2 (comparison): Production of a TRV component by means of single pieces obtained by precision casting and assembly by welding</u>

A TRV component with the same dimensions as the one in EXAMPLE 1 was made by producing six wedges and the two flanges obtained by precision casting.

The making of the single pieces and the subsequent assembly by welding, including the closing of the holes of the blades, required about one month.

Although the outer surfaces of the single pieces already had a roughness index close to the desired one (about 3.2 RA), it was necessary to subject all of the single weldings carried out for the assembly of the pieces and the closure of the holes of the blades to mechanical and polishing processes.

After the mechanical flattening and hole-recovery processes, the final component had an overall weight of about 80 kg, with the walls of the cavities of the blades with a thickness greater than 1.8mm.

Various modifications can be made to the embodiments described herein without departing from the scope of the present invention. For example, in addition to the nickel-based alloys specifically mentioned in the present description, the process of the present invention can be applied to the production of components of large dimensions and/or complex geometries with other suitable alloys depending on the various uses provided for the component. Moreover, the powders can also be deposited by making the mobile build plate 30 rotate and by maintaining the distributor device 40 fixed, or by combining the rotary movement of one with respect to the other.

CLAIMS

1. A process for the production of a monolithic metal component for turbine engines, wherein the component is essentially cylindrical in shape and wherein it is obtained in a laser beam powder-bed fusion apparatus comprising a fusion chamber housing a mobile build plate movable at least along a direction parallel to the axis of the monolithic component to be produced, and at least one mobile powder distributor, the process comprising the steps of:

a) generating a three-dimensional mathematic model of said component;

b) storing the three-dimensional mathematic model of said component in a control unit of the apparatus;

c) preparing the powders of the metal material to be used;

d) depositing a quantity of said powders in said fusion chamber of the apparatus to form a layer of powders with a regular and substantially uniform thickness;

e) heating and maintaining the fusion chamber of the laser beam powder-bed fusion apparatus at a temperature below the fusion temperature of said powders;

f) melting, by means of laser beams, said layer of powders deposited during step d) by scanning the area corresponding to a layer of said component, according to the three-dimensional model stored in the control unit of said fusion apparatus;

g) injecting a flow of inert gas at the layer as soon as it is melted in said step f);

h) repeating said steps from d) to g) until reaching the last layer of said component according to the three-dimensional model stored in said control unit,

wherein said powders are deposited in said step d) with a rotary motion around the axis of said component and said laser beams are oriented in said step f) towards the powder layer just deposited in said step d),

characterized by the steps of:

- simulating the building of said component between said steps a) and b); and
- monitoring in situ each last melted layer after said step g) before repeating said steps from d) to g).

2. The process according to claim 1, wherein said flow of inert gas is injected, in said step g), along a radial direction moving away from the axis of said component.

3. The process according to claim 1 wherein, in said step d), said powders are

deposited by rotating said mobile powder distributor around the axis of said component.

4. The process according to claim 1 wherein, in said step d), said powders are deposited by rotating said mobile build plate around the axis of said component.

5. The process according to claim 1, wherein, after said step c), the prepared powders are stored in a protective atmosphere before being loaded in said laser beam powder-bed fusion apparatus.

6. The process according to claim 1, wherein, at the end of the building process, the component remains attached to the build plate, and wherein the component and the build plate are transferred in a vacuum furnace to perform a stress relieving heat treatment of the component.

7. The process according to claims 1 to 6, wherein the component is separated from said build plate by wire cutting in an electrical discharge machine.

8. The process according to claim 7, wherein a heat treatment of the component is carried out in a vacuum furnace to fix the desired microstructure of the component.

9. The process according to claim 1, wherein the particle size of said powders ranges from 10 to 150 μm.

10. The process according to claim 1, wherein said powders are obtained by means of gas or plasma atomization processes.

11. The process according to claim 1, wherein said metal material is a nickel-based alloy selected among RENE' 220, HAYNES 282, INCONEL 718 and RS5.

12. The process according to claim 1, wherein said powders have the same chemical composition as the material with which said component is made.

13. The process according to claim 1, wherein the programming of the power of said laser beams and of the scanning speed of said beams, before said step f), is provided.

14. The process according to claims 1 to 13, wherein said monolithic metal component for turbine engines is a "turbine rear vane" or a "turbine rear frame" provided with a flange on one or both of its ends, and wherein each of said flanges is processed in a milling machine after the separation of the component from the build plate.

15. A component made through a process according to any one of claims 1 to 14 and resulting in a monolithic component of a turbine engine for aeronautical use, selected from a "turbine rear vane" and a "turbine rear frame," wherein the monolithic component includes blades with inner cavities with structural wall thickness ranging between 1 and 1.8 mm.

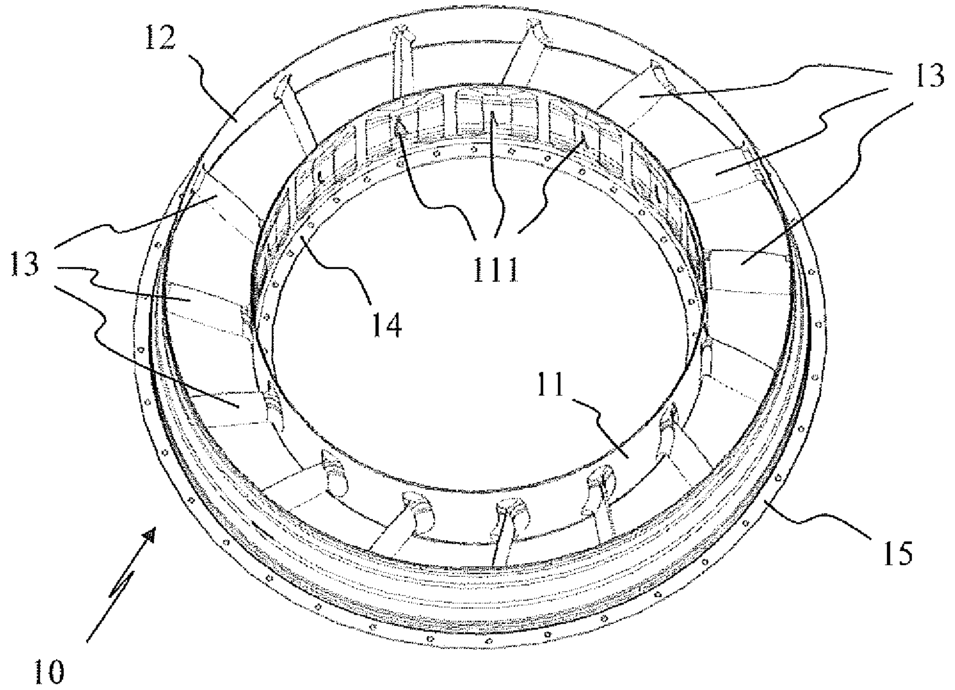

Fig. 1

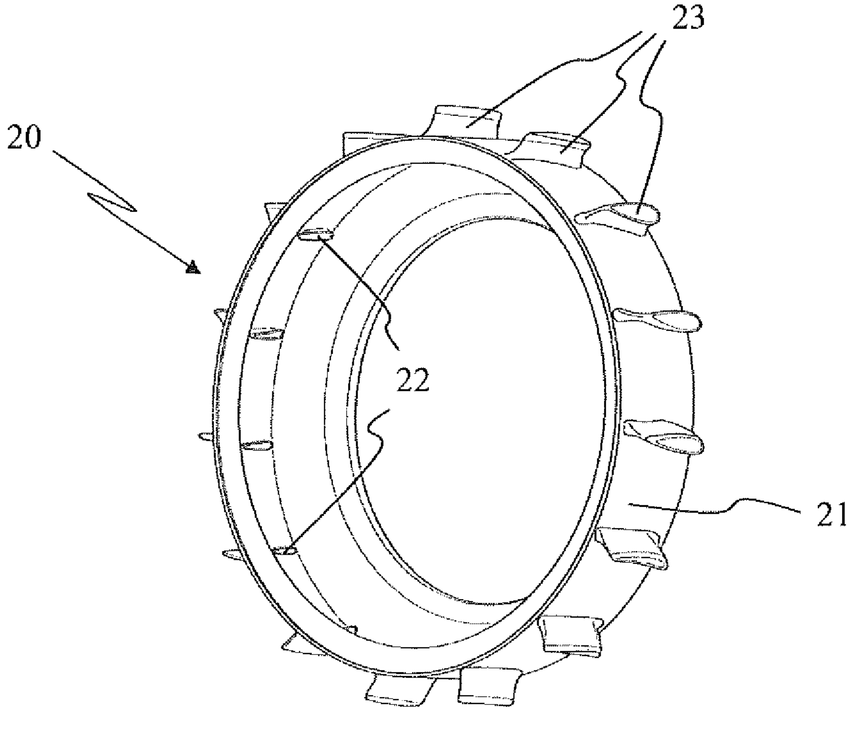

Fig. 2

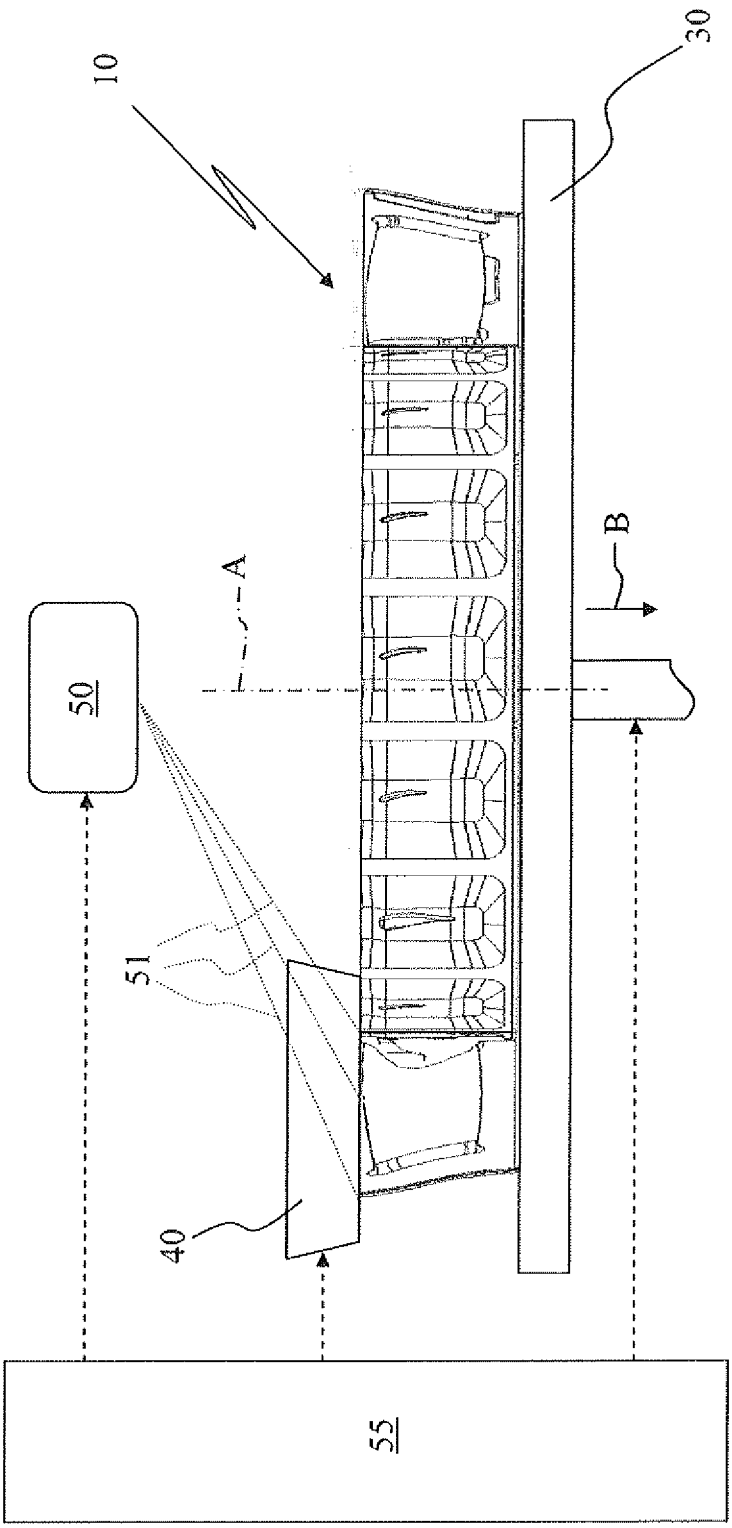

Fig. 3

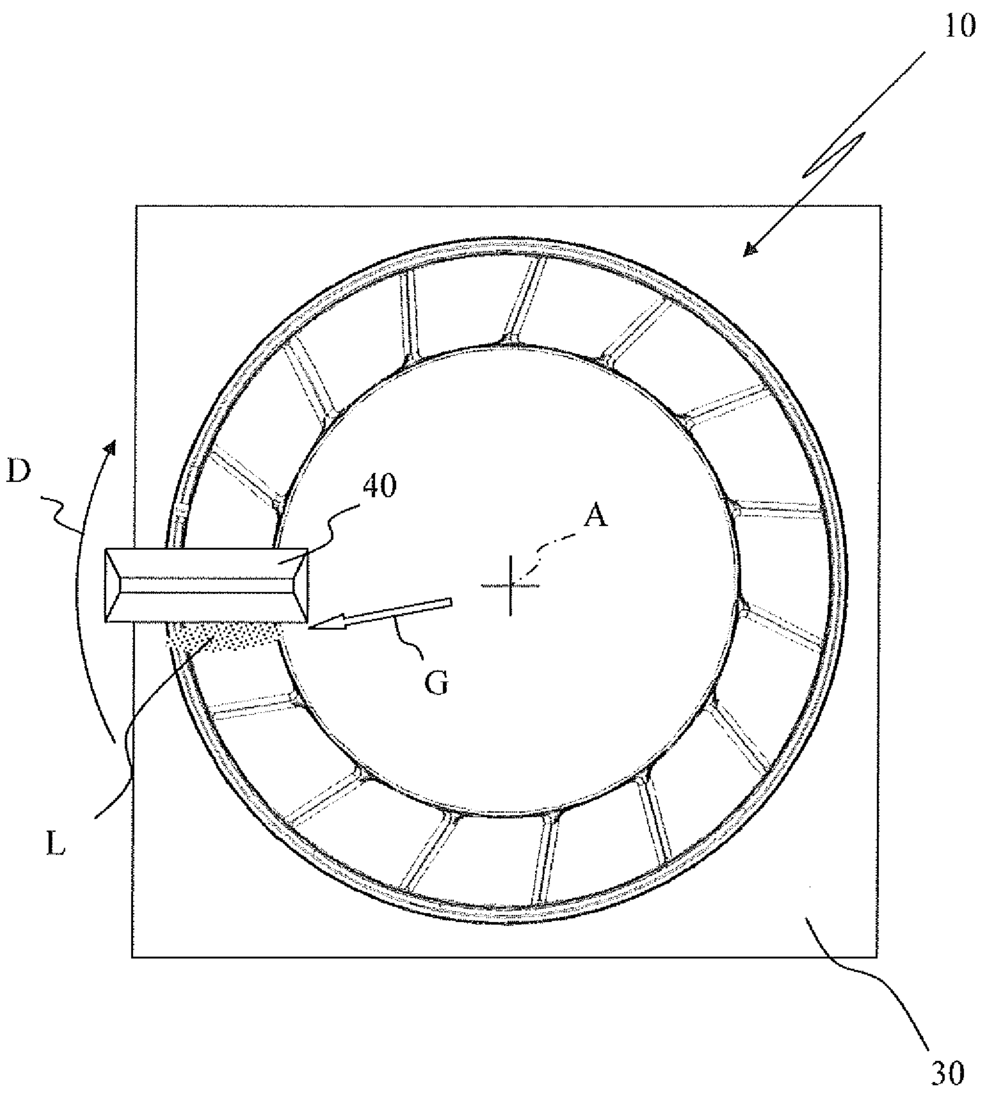

Fig. 4

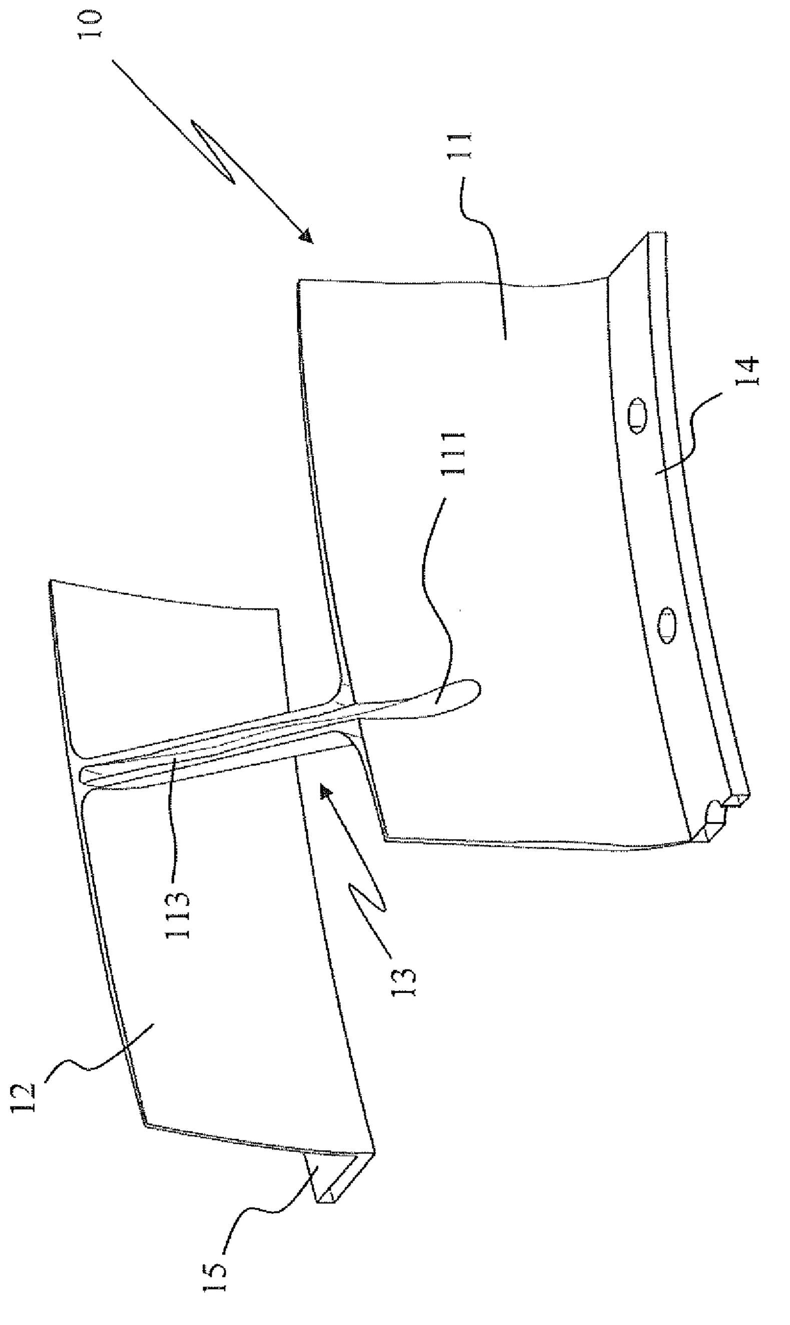

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2019/051758

A. CLASSIFICATION OF SUBJECT MATTER
INV. B22F3/105 B23K26/08 B23K26/12 B33Y80/00 B33Y10/00
B23K26/342 B23K26/70 B23K26/142 F01D5/14 F01D9/04
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 B23K B33Y F01D

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.
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A	paragraphs [0001], [0007] - [0020], [0022], [0027] - [0032], [0037] - [0041]; claims; figures	1
X	EP 2 708 296 A2 (HONEYWELL INT INC [US]) 19 March 2014 (2014-03-19)	15
A	paragraphs [0001], [0005] - [0008], [0022], [0026] - [0048]; claims; figures	1
Y	GB 2 543 305 A (ROLLS ROYCE PLC [GB]) 19 April 2017 (2017-04-19) paragraphs [0001], [0005], [0007] - [0008], [0015], [0019] - [0025], [0031] - [0036], [0042]; claims; figures	1-14

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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 :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"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
7 August 2019	19/08/2019

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	Ceulemans, Judy

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	CRIALES LUIS E ET AL: "Laser powder bed fusion of nickel alloy 625: Experimental investigations of effects of process parameters on melt pool size and shape with spatter analysis", INTERNATIONAL JOURNAL OF MACHINE TOOLS AND MANUFACTURE, ELSEVIER, AMSTERDAM, NL, vol. 121, 18 March 2017 (2017-03-18), pages 22-36, XP085133020, ISSN: 0890-6955, DOI: 10.1016/J.IJMACHTOOLS.2017.03.004 the whole document -----	1-14
A	EP 3 031 552 A2 (BOEING CO [US]) 15 June 2016 (2016-06-15) paragraphs [0001] - [0006], [0015] - [0033], [0072] - [0074], [0187] - [0190]; claims; figures -----	1-14

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