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(54) FORMING A COMPOSITE COMPONENT

FORMUNG EINER VERBUNDKOMPONENTE

FORMAGE D'UN COMPOSANT COMPOSITE

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(56) References cited:
EP-A1- 0 072 175 **EP-A2- 1 724 438**
JP-A- H 067 916 **US-A1- 2013 294 901**

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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a method of forming a composite component, in which a plurality of feed materials are initially in a powdered state and a solid component is formed by the application of heat.

[0002] The present invention also relates to an apparatus for forming a composite component, of the type in which a plurality of feed materials are initially in a powdered state and a solid component is formed by the application of heat.

2. Description of the Related Art

[0003] Composite components are component parts made from two or more dissimilar materials that are consolidated to produce a single structure with characteristics different from the individual constituent materials. The composite structure may be preferred for a number of reasons for example in creating a multi-layer component having a hard exterior surface but a low density, light-weight interior.

[0004] JPH 06 7916 (Kiyadeitsuku Technol Service K) shows an example casting method to create this type of composite component in which a mixture of two powdered materials is added into a mould cavity and utilises an induction coil so as to melt the powder mixture so as to control the melting and solidifying and thus microstructure of the final component.

[0005] A variety of methods are known for producing a multi-layer component comprising one or more dissimilar materials, such as hard facing or laser cladding.

[0006] However these known methods incur a number of problems. Firstly, a disadvantage is experienced in the number of separate processes required to create the finished component. Secondly, such techniques of applying a layer of material to the exterior of a solid object result in a non-discreet join of the two materials, leading to a structural weakness at the interface.

[0007] US 2013/294901 A1 (Mironets et al) shows a method of component forming which includes positioning a metal powder into a cavity before being melted in an induction furnace. This document also suggests using component strengthening structures which are held in position by the component once the component has been formed. A further method is shown in EP 1 724 438 A2 (General Electric) in which a slip case is used in the casting method which separates the two different powdered materials. The slip case is then removed to allow the powdered materials to mix before solidification.

[0008] EP 0 072 175 A1 (Mowill) is an example of a hot isostatic process in which a basket is placed within an enclosure to provide two separate regions for different powders or alloys. The basket allows for diffusion of the two alloys as the alloys begin to melt. The basket may be removed once the component is formed or melted and evaporated.

BRIEF SUMMARY OF THE INVENTION

[0009] According to a first aspect of the present invention, there is provided a method of forming a composite component from a plurality of dissimilar powdered feed materials comprising the steps of; obtaining a negative ceramic mould of a component defining a first aperture associated with a first region of the mould and a second aperture associated with a second region of the mould; deploying a first powdered feed material into said first region of the negative mould via the first aperture and a second powdered feed material into said second region of the negative mould via the second aperture; preventing diffusion of said first feed material with said second feed material by means of a partition separating said first region and said second region; increasing the temperature within said negative mould to a first temperature causing said first feed material to melt during a heating stage; and melting said partition to allow diffusion of said first feed material with said second feed material.

[0010] According to a second aspect of the present invention there is provided an apparatus for forming a composite component from a plurality of dissimilar powdered feed materials comprising; a negative ceramic mould defining a first aperture associated with a first region of the mould and a second aperture associated with a second region of the mould; wherein said first aperture is configured for insertion of a first powdered feed material into said first region of the mould and said second aperture is configured for insertion of a second powdered feed material into a second region of the mould; and said negative ceramic mould is suitable for heating to a first temperature during a heating stage, characterised in that: said negative ceramic mould further comprises a partition separating said first and said second regions, said partition configured to prevent diffusion of said first feed material with said second feed material when in a solid form and further configured to melt to allow diffusion of said first feed material with said second feed material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011]

Figure 1 shows a method of forming a composite component from powdered feed materials;
Figure 2 shows a procedure for the creation of a negative mould;
Figure 3 shows the deployment of feed materials together in the mould of Figure 2;
Figure 4 shows a feeder section of a negative mould;
Figure 5 shows the negative mould of Figure 4 after solidification;
Figure 6 shows a mould with two regions and two

feed materials being inserted separately;

Figure 7 shows the mould of Figure 6 after heating to join the feed materials;

Figure 8 shows a cross section view of a first mould with a partition;

Figure 9 shows in cross section a second mould with a partition;

Figure 10 shows a processing apparatus;

Figure 11 shows a temperature-time graph for the process of Figure 8;

Figure 12 shows a temperature-time graph for the process of Figure 9.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

Figure 1

[0012] A method of forming a composite component from powdered feed materials falling outside the claimed invention is illustrated in Figure 1, in which a solid component is formed from a plurality of dissimilar powdered feed materials by the application of heat.

[0013] At step **101,** a negative mould **102** is obtained that defines the profile of a component to be produced. At step **103,** the powdered feed materials, first feed material **104** and second feed material **105** are deployed into the negative mould. At step **106,** heat is applied to the mould increasing the temperature and causing the powdered feed materials to melt during a heating stage. At step **107** the temperature is maintained where necessary to allow diffusion of first feed material **104** with second feed material **105.** At step **108** the temperature is decreased, causing the molten feed materials to solidify during a cooling stage.

Figure 2

[0014] As discussed with reference to step **101** of the method of Figure 1, a negative mould is obtained from a positive model of a component.

[0015] A method of obtaining a negative mould is illustrated in Figure 2. A positive model **201** is created from an appropriate medium such as a rapid prototyping material, polystyrene or wax, defining the geometry of the desired component.

[0016] Negative mould **102** is then formed around the positive model to define a negative profile of the component. In a first embodiment, the negative mould comprises a layer of material having a melting point higher than that of first feed material **104** and second feed material **105,** such as a very high temperature ceramic material. The ceramic shell is created by applying a plurality of layers of ceramic slurry to the exterior of the positive model, until the required wall thickness is achieved.

[0017] The sacrificial positive model material **201** is then evacuated from the negative mould **102** via aperture **202** using an appropriate removal technique, such as the application of heat and/or a solvent. This leaves a cavity **203** defining the exterior surface of the component.

Figure 3

[0018] Step **103** of the method of Figure 1 for the deployment of feed materials is illustrated in Figure 3. The positive sacrificial model **201** has been removed as shown previously with reference to Figure 2, leaving negative mould **102** ready to receive feed material, such as first feed material **104** and second feed material **105** contained within feed device **301.** In an embodiment the filling of negative mould **102** is facilitated by vibration of the mould to encourage the powdered feed materials to settle. Negative mould **102** is placed upon vibrating table **302,** itself supported by stable base member **303.** In this way, as powdered feed materials are introduced to the mould they tend to compact under gravity.

[0019] In the embodiment illustrated in Figure 3 first feed material **104** and second feed material **105** have been combined in powder form in feed device **301,** prior to introduction to the mould. This type of powder preparation is advantageous as it allows for very precise material compositions and uniform dispersions of particles before agglomeration. First feed material **104** comprises a metallic melt powder with a first melting point and second feed material **105** comprises a ceramics substance with a much higher melting point than that of first feed material **104.**

[0020] Thus, in the illustrated embodiment first feed material **104** and second feed material **105** are deployed into the mould together via aperture **202** so as to fill cavity **203** within negative mould **102,** and then heated as in step **106** during a heating stage. The temperature is increased by heating the negative mould **102** to a first temperature, approximately equal to the melting point of first feed material **104,** thereby causing first feed material **104** to melt. However second feed material **105,** having a melting point much higher than that of the first temperature is not melted and remains in its solid particulate form.

[0021] In alternative embodiments the heating stage described above is performed in a pressure controlled environment at a pressure other than atmospheric pressure of 1 bar. In a first embodiment the pressure is reduced to below atmospheric pressure by removing air from the pressure controlled environment. In a second embodiment the applied pressure is increased to a level above atmospheric pressure. Equally the heating stage may be performed under time-evolving pressure conditions.

Figure 4

[0022] A negative mould **401,** substantially similar to negative mould **102,** of Figure 3 is shown in partial cross section in Figure 4 after deploying step **103** and heating step **106.** As previously described with reference to Figure 3, negative mould **401** has been heated to a first temperature thereby melting first feed material **104** whilst second feed material **105** is not melted but remains uniformly distributed throughout the casting. In this embodiment mould **401** includes a component section **402** and a feeder section **403.** The feeder section **403** defines a generally cylindrical passageway **404,** extending from a first open end **405** and entering the component section **402** at a second end **406** via aperture **407.**

[0023] Feeder section **403** feeds additional liquefied material into negative mould **401** during cooling stage **108** as the molten material contained within negative mould **401** contracts in volume. When materials cool from their molten liquid phase, their volume reduces as the temperature decreases to the point at which they become solid. Therefore feeders are used to provide liquefied material to compensate for the shrinkage cavities that would otherwise form at one or more thermal centres in the interior of the casting. Therefore the volume of the liquefied material in feeder section **403** is determined by the requirement for sufficient liquid material to be provided in order to compensate for the volume reduction of the material as it cools. During solidification the material contracts typically by about 7% by volume and consequently an equal volume of liquefied material enters the component section from the feeder section.

[0024] The efficiency of the feeder section **403** is influenced by the static pressure in the feeder, resulting from the amount of liquefied material it holds and its vertical height. The static pressure head assists in forcing the liquefied material into the casting as it cools. Moulds in accordance with this preferred embodiment have one or more feeders that are sufficiently tall such that during production of the composite component, the height of liquefied material within the feeder remains above the tallest part of the component section of the mould. This allows sufficient pressure to be exerted on the molten material within the mould as to ensure that any fine features defined by the mould are reproduced.

Figure 5

[0025] As previously discussed with reference to Figure 4, in an embodiment only first feed material **104** is melted whilst second feed material **105** remains in its solid form. Figure 5 shows negative mould **401** after cooling stage **108** whereby the temperature within the mould has decreased to below the first temperature causing said first feed material to solidify and the volume of liquefied material within the feeder section has reduced to level **501.** Therefore after cooling step **108,** the molten first feed material **104** solidifies consolidating said second feed material particles **105** within the bulk casting providing structural locking. In this way composite components may be produced that exhibit improved tensile and impact strengths, compared to those components with a uniform composition.

[0026] Unlike negative mould apparatus of the prior art, in the illustrated embodiment negative mould **401** is not hermetically sealed during heating stage **106** and cooling stage **108.** Moulds of the prior art compensate for a reduction in volume of feed materials during temperature changes by plastically deforming. In an embodiment negative mould **401** is substantially rigid and is configured to be incompressible so as not to deform during heating stage **106** and cooling stage **108.** In order to account for fluctuations in volume of the material within the negative mould during temperature changes, negative mould **401** is configured to be pervious to the atmosphere during use. Therefore negative mould **401** exchanges volume with the atmosphere via aperture **407** and feeder section **403.** However, in an alternative embodiment negative mould **401** is hermetically sealed after deploying stage **103** and prior to heating stage **106,** by capping feeder section **403** to prevent interaction with the atmosphere.

[0027] In alternative embodiments the cooling stage may be conducted under pressure conditions other than atmospheric pressure, or applied pressure may be varied as a function of time. Altering the pressure under which the material solidifies can influence the crystal structure of the casting. Solidifying during the cooling stage under increased pressure conditions is likely to result in a denser and more structurally uniform casting, enhancing the impact properties of the component.

Figure 6

[0028] The negative moulds **102** and **401** described with reference to Figures 1 to 5 have only a first aperture and corresponding feeder section to allow deployment of feed materials into the mould. These embodiments fall outside the present invention. However in an alternative embodiment in accordance with the present invention, a mould is provided which has more than one aperture for deployment of feed materials separately into different regions of the mould.

[0029] An example of such a mould is shown in cross section in Figure 6. The mould **601** has a first region **602** and a first aperture **603** associated with said first region **602,** and a second aperture **604** associated with a second region **605.** Similar to mould **102,** mould **601** also includes feeder sections **606** and **607** extending from respective apertures.

[0030] First feed material **608** is deployed into first region **602,** via first aperture **603** and feeder section **606.** Second feed material **609** is deployed separately to said first feed material **608** into second region **605,** via second aperture **604** and feeder section **607.** This results in a casting with different materials localised to different regions of the component. The feed materials are deployed into their respective regions at roughly the same rate therefore they meet at an interface **610** that is approximately equidistant between first aperture **603** and second aperture **604.**

Figure 7

[0031] Negative mould **601** previously discussed with reference to Figure 6 is shown in Figure 7 during the application of heat. In this embodiment first feed material **608** and second feed material **609** are both metallic melt powders, therefore are melted when the temperature of mould **601** is increased to their respective melting points.

[0032] First feed material **608** is a metal powder with a melting temperature of 700°C and second feed material **609** is a different metal powder with a melting temperature of 1000°C.

[0033] Heat is applied to negative mould **601** as indicated by the arrows, so as to raise its temperature to a first temperature, approximately equal to the melting point of the first feed material. Therefore first feed material **608** is melted within first region **602.** The temperature is further increased to a second temperature approximately equal to the melting point of second feed material **609,** thereby melting second feed material **609.**

[0034] In an embodiment said first feed material **608** is joined to said second feed material **609** by selective alloying through solid state diffusion of the particles.

[0035] At this point both first feed material **608** and second feed material **609** are in their molten liquid states and thus diffusion occurs resultant of the Brownian motion of the particles. At the interface **610** some of the particles of first feed material **608** deployed in first region **602** drift rightwards into second region **605.** Similarly particles of second feed material **609** drift leftwards from second region **605** into first region **602,** thereby alloying said first feed material **608** to said second feed material **609** across an alloyed region **701** about the interface **610.**

[0036] The extent to which said first feed material **608** is alloyed to said second feed material **609** is controlled by the diameter **d** of the alloyed region **701.** The diameter **d** of alloyed region **701** is dictated by the distance to which the particles are allowed to diffuse into the adjacent region. This is dependent on the energy of the particles, itself a function of the temperature, and the time period for which the feed materials are in their molten state.

[0037] In the illustrated embodiment the second temperature is maintained during step **107,** for a time period of 10 seconds, so as to allow diffusion of particles over an alloyed region of diameter **d.** When the desired degree of alloying is achieved the temperature of negative mould **601** is decreased to below the melting points of the feed materials thereby preventing excessive diffusion of the molten materials.

[0038] Therefore once solidified a component is produced with a non-uniform metallurgy along its length, with a discreet interface between the different regions of material. In this way the component enjoys the functional benefits of both first feed material **608** and second feed material **609,** whilst maintaining the structural properties of a single casting.

Figure 8

[0039] An example of a component produced by a process embodying the present invention is illustrated in cross section in Figure 8. Figure 8 shows a negative mould **801,** similar in construction to negative mould **601** of Figures 6 & 7, in that the moulding defines a component comprising a first region **802** and a second region **803,** accessed by apertures **804** and **805** respectively. First region **802** is filled with first feed material **806** which is a titanium powder and second region **803** is filled with second feed material **807** which is a titanium carbide powder.

[0040] Additionally negative mould **801** comprises a partition **808** thereby dividing first region **802** and second region **803.** Partition **808** is a titanium sheath that is approximately 2mm in thickness and completely separates first region **802** from second region **803.**

[0041] When producing more complex components using powder pressing techniques a problem is experienced in terms of maintaining the positioning of the feed materials, to prevent gravitational sedimentation or incidental dispersion in the powder phase prior to melting. By including partition **808** first feed material **806** in first region **802** is prevented from migrating into second region **803** and diffusing with second feed material **807** until partition **808** is melted.

[0042] In this embodiment the object to be produced is a rack component corresponding to a rack and pinion arrangement, used for transforming the rotational motion of a toothed pinion gear into linear motion of the splined rack. The splined surface of the rack component is repeatedly subjected to a torque exerted by the pinion gear; therefore must be extremely hard so as to be resistant to material degradation. However, additionally the component must be relatively lightweight.

[0043] Thus, it is desirable to have a first region of the component composed of a substance that is sufficiently lightweight, such as titanium, but wherein the driving splines have an increased surface hardness for example by using a titanium carbide powder.

[0044] In the illustrated embodiment first feed material **806** second feed material **807** and partition **808** each have a melting point corresponding to a first temperature. Therefore upon application of heat to a first temperature, as in step **106** and described with reference to figure 7, first feed material **806,** second feed material **807** and partition **808** are melted, thereby allowing interaction of the molten feed materials in the opposing regions.

[0045] As in step **107** the temperature is maintained for a period of time to allow a diffusion layer of sufficient diameter as to create a discreet interface between first feed material **806** and second feed material **807** to form.

[0046] When the diffusion layer forming the alloyed region is the desired diameter the temperature is decreased to below said first temperature, causing the casting to solidify during a cooling stage.

[0047] Although cooling at a natural rate may be suitable for some materials, others may require accelerated cooling. In an embodiment the temperature of the mould is decreased rapidly by forcing an inert gas such as argon or helium to flow over the negative mould **801.**

Figure 9

[0048] A fifth example of a mould embodying the present invention is shown in Figure 9. Mould **901** for producing a gas turbine blade component is illustrated comprising a first region **902** innermost, contained within partition **903** and a second region **904** outermost.

[0049] Similarly to Figure 8, first region **902** is fed via first feeder section **905** through first aperture **906,** and second region **904** is fed through second feeder section **907** and second aperture **908.**

[0050] In an embodiment of the invention partition **903** is invested within the positive wax model of the component, as shown with reference to Figure 2 during construction of mould **901.** Therefore when the sacrificial material forming the positive model is removed partition **903** remains inside negative mould **901** supported by feeder section **905.**

[0051] In the illustrated embodiment first feed material **909** in first region **902** and second feed material **910** in second region **904** are metallic powders. First feed material **909** is a low density metal powder such as aluminium with superior thermal conductivity characteristics, whilst second feed material **910** is a high density metal such as steel with increased surface hardness. First feed material **909** and second feed material **910** both have a melting point corresponding to a first temperature.

[0052] Partition **903** comprises a third material such as nickel which is beneficial to the alloying process, and having a melting point corresponding to a second temperature, higher than the first temperature.

[0053] Therefore when the temperature of mould **901** is increased to the first temperature, both first feed material **909** and second feed material **910** are melted, however they are separated by partition **903** which remains in solid form. Further increasing the temperature of the negative mould **901** to the second temperature causes the partition **903** to be melted, thereby allowing diffusion of first feed material **909** with second feed material **910,** creating an alloyed region comprising both first feed material aluminium particles, second feed material steel particles and partition material nickel particles.

[0054] By altering the composition of the material used to create partition **903** it is possible to influence the melting point and therefore alloying temperature of the various feed materials.

[0055] In an embodiment the partition **903** is formed of a ceramic material having a melting point far greater than the melting points of the feed materials. Therefore the alloying process is conducted at a greatly increased temperature, resulting in a more uniform crystalline structure of the alloyed region.

[0056] Although the invention has been described by embodiments present using only two powdered feed materials, it will be appreciated that in alternative embodiments any number of dissimilar feed powders may be used.

[0057] Equally components may be created with any number of different localised regions of dissimilar materials, accessed by any number of apertures for insertion of feed materials. Indeed in a yet further alternative embodiment of the present invention a multi-core rod component is formed, comprising ten regions separated by nine partitions into which ten dissimilar feed materials are deployed.

Figure 10

[0058] Apparatus for performing the processing method embodying the present invention in which moulds such as negative mould **901,** containing powdered feed materials are processed to form a composite component, is illustrated in Figure **10.**

[0059] The apparatus **1001** comprises a vacuum furnace **1002,** creating a vacuum-tight chamber **1003** and having a door **1004** to allow loading and unloading of the chamber **1003.**

[0060] In an embodiment vacuum furnace **1002** includes means for varying the temperature and pressure within. Vacuum furnace **1002** has a heat source for producing radiant heat such as resistance heating element **1005,** which is connected to power supply **1006.**

[0061] The apparatus **1001** also includes a vacuum pump **1007** connected to chamber **1003** for evacuating air from the chamber **1003** such that the pressure in the chamber may be reduced to below atmospheric pressure. Additionally a compressor **1008** is also provided so as to allow the pressure inside the chamber **1003** to be increased above atmospheric pressure.

[0062] Electronic controller **1009** is provided comprising temperature sensor **1010** and pressure sensor **1011** and associated wiring. Temperature sensor **1010** is located within chamber **1003** and is configured to provide signals indicative of the actual temperature within chamber **1003.** Similarly pressure sensor **1011** is configured to provide an indication of the air pressure within the chamber **1003.**

[0063] Electronic controller **1009** is configured to receive signals from temperature sensor **1010** and pressure sensor **1011,** and modulate the power supply **1006** for the resistance heating element **1005,** vacuum pump **1007** and compressor **1008** accordingly. In an embodiment, controller **1009** is a programmed computer system or microcontroller.

[0064] In an embodiment of the invention it is desirable that the cooling stage is accelerated to cause the molten feed materials to decrease in temperature and solidify more rapidly. Therefore compressor **1008** is used to force an inert gas, such as nitrogen into vacuum chamber **1003** whilst vacuum **1007** evacuates the spent gas, thereby creating a cooling convection current over negative mould **901.**

Figure 11

[0065] An example of process steps **106-108** embodying an aspect of the present invention as illustrated in Figure 8 is depicted by the graph of Figure 11. The graph **1101** shows a plot of temperature (T) as a function of time (t).

[0066] Initially at time **1102** the chamber of vacuum furnace **1002** is at ambient temperature **1103.** Electrical power is then supplied to the resistance heating coils, at time **1104** until time **1105** to raise the temperature within the chamber to a first temperature **1106,** above the melting point of first feed material **806,** second feed material **807** and partition **808,** thereby establishing molten liquid within mould **801.**

[0067] The increased temperature **1106** is stably maintained between times **1105** and **1107,** thereby maintaining the feed materials in their molten state and enabling a degree of diffusion at the interface.

[0068] When the period of time that has elapsed is sufficiently long to allow a suitable amount of diffusion between first feed material **806** and second feed material **807,** creating an alloyed region of desired diameter, power to the resistance coils is interrupted and heating stops.

[0069] At time **1107** the power is cut-off and the chamber is allowed to cool naturally, until at time **1108** the temperature has returned to ambient temperature **1103,** the casting has solidified and may now be removed from the chamber.

Figure 12

[0070] A second example of process steps **106-108** embodying the aspect of the invention as illustrated in Figure 9, is shown by graph **1201** in Figure 12.

[0071] Again at time **1102** the vacuum furnace chamber is at ambient temperature **1103.** At time **1104** the heating stage begins and the temperature of the chamber increases until the first temperature **1106** at time **1105.** At this stage first feed material **909** and second feed material **910,** both having melting temperatures below first temperature **1106,** have been melted and are in their molten state.

[0072] However as discussed with reference to Figure 9, partition **903** has a higher melting point than either first feed material **909** or second feed material **910,** therefore remains in its solid phase. Therefore in this embodiment heating continues for a further period of time, until time **1202** when the temperature has increased to second temperature **1203** and the partition is melted. At this stage both first feed material **909,** second feed material **910** and partition **903** are in molten states and begin to diffuse at the interface. In this embodiment it is desirable that the alloyed region created by the diffusion of particles is relatively larger in diameter than the alloyed region created in the process shown in Figure 11. Therefore the increased temperature is maintained for a longer period of time, from time **1202** until time **1203,** thereby allowing a greater degree of particle diffusion. At time **1203** the alloyed region is of adequate diameter and therefore power to the heating coil is interrupted and cooling begins.

[0073] In this embodiment it is desirable that the cooling stage is accelerated. Therefore at time **1203** compressor **1008** and vacuum **1007** are configured to force a convection current over the negative mould **901,** as described with reference to Figure 10 during the cooling step of **108.** This results in a rapid decrease in temperature of negative mould **901** and consequently solidification of the molten feed materials occurs quickly. At time **1204** the temperature in the chamber has returned to ambient temperature **1003** and the mould may be removed from the chamber and further processed if necessary.

Claims

1. A method of forming a composite component from a plurality of dissimilar powdered feed materials, comprising the steps of:

obtaining a negative ceramic mould (102, 401, 601, 801, 901) of a component defining a first aperture (603, 804, 906) associated with a first region (602, 802, 902) of the mould and a second aperture (604, 805, 908) associated with a second region (605, 803, 904) of the mould;
deploying a first powdered feed material (104, 608, 806, 909) into said first region of the negative mould via the first aperture and a second powdered feed material (105, 609, 807, 910) into said second region of the negative mould via the second aperture;
preventing diffusion of said first feed material with said second feed material by means of a partition (808, 903) separating said first region and said second region;
increasing the temperature within said negative mould to a first temperature (1106) causing said first feed material to melt during a heating stage (106); and
melting said partition to allow diffusion of said first feed material with said second feed material.

2. The method of claim 1, wherein said partition is melted when the temperature of said negative mould is increased to said first temperature during said heating stage.

3. The method of claim 1 or claim 2, wherein said second feed material is melted during said heating stage.

4. The method of any of claims 1 to 3, wherein said first powdered feed material diffuses with said second powdered feed material during said heating stage to join said first and second powdered feed materials.

5. The method of any of claims 1 to 4, wherein said first feed material and said second feed material are metals.

6. The method of claim 5, wherein said first feed metal is joined to said second feed metal by diffusion of the particles during said heating stage to alloy said first and second metals over an alloyed region (701) at the interface (610).

7. The method of any of claims 1 to 6, further comprising the step of:

decreasing the temperature within said negative mould to below said first temperature causing said first feed material to solidify during a cooling stage (108).

8. The method of claim 7, further comprising the step of:

feeding additional liquefied material into said negative mould during said cooling stage as the material contained within said negative mould contracts in volume.

9. The method of any of claims 1 to 8, wherein said heating stage is performed under a pressure other than atmospheric pressure.

10. The method of any of claims 7 to 9, wherein said cooling stage is performed under a pressure other than atmospheric pressure.

11. The method of any of claims 1 to 10, wherein the temperature within said mould is increased to a second temperature (1203) during said heating stage.

12. The method of claim 11, wherein said partition is melted when the temperature of said negative mould is increased to said second temperature during said heating stage.

13. An apparatus for forming a composite component from a plurality of dissimilar powdered feed materials, comprising:

a negative ceramic mould (102, 401, 601, 801, 901) defining a first aperture (603, 804, 906) associated with a first region (602, 802, 902) of the mould and a second aperture (604, 805, 908) associated with a second region (605, 803, 904) of the mould; wherein;
said first aperture is configured for insertion of a first powdered feed material (104, 608, 806, 909) into said first region of the mould and said second aperture is configured for insertion of a second powdered feed material (105, 609, 807, 910) into a second region of the mould; and
said negative ceramic mould is suitable for heating to a first temperature (1106) during a heating stage(106), **characterised in that**: said negative ceramic mould further comprises a partition (808, 903) separating said first and said second regions, said partition configured to prevent diffusion of said first feed material with said second feed material when in a solid form and further configured to melt to allow diffusion of said first feed material with said second feed material.

14. The apparatus of claim 13, wherein said negative ceramic mould is configured to be pervious to the atmosphere in use.

Patentansprüche

1. Ein Verfahren zum Herstellen einer Verbundkomponente aus einer Vielzahl unterschiedlicher Einsatzmaterialien in Pulverform, bestehend aus folgenden Schritten:

Herstellen einer Negativform aus Keramik (102, 401, 601, 801, 901) für eine Komponente, wobei eine erste Öffnung (603, 804, 906) als Zugang für eine erste Region (602, 802, 902) der Form sowie eine zweite Öffnung (604, 805, 908) als Zugang für eine zweite Region (605, 803, 904) der Form dient;
Einfüllen des ersten Einsatzmaterials in Pulverform (104, 608, 806, 909) in diese erste Region der Negativform über die erste Öffnung und eines zweiten Einsatzmaterials in Pulverform (105, 609, 807, 910) in die genannte zweite Region der Negativform über die zweite Öffnung;
Verhindern des Eindringens des genannten ersten Einsatzmaterials in das zweite Einsatzmaterial mithilfe einer Trennvorrichtung (808, 903), die die oben beschriebene erste und zweite Region voneinander trennt;
Erhöhen der Temperatur in dieser Negativform auf eine erste Temperatur (1106), durch die das erste Einsatzmaterial während eines Erwärmungsvorgangs (106) schmilzt; und
Schmelzen der genannten Trennvorrichtung, sodass das oben genannte erste Einsatzmaterial in das oben beschriebene zweite Einsatzmaterial eindringen kann.

2. Das Verfahren nach Patentanspruch 1, wobei die Trennvorrichtung schmilzt, sobald die Temperatur der Negativform auf die oben beschriebene erste Temperatur des Erwärmungsvorgangs ansteigt.

3. Das Verfahren nach Patentanspruch 1 oder 2, wobei das zweite Einsatzmaterial während des Erwärmungsvorgangs schmilzt.

4. Das Verfahren nach den Patentansprüchen 1 bis 3, wobei das genannte erste Einsatzmaterial in Pulverform während der beschriebenen Erwärmungsphase in das zweite Einsatzmaterial in Pulverform eindringt, sodass sich erstes und zweites Einsatzmaterial in Pulverform vermengen.

5. Das Verfahren nach den Patentansprüchen 1 bis 4, wobei es sich beim beschriebenen ersten Einsatzmaterial und dem beschriebenen zweiten Einsatzmaterial um Metalle handelt.

6. Das Verfahren nach Patentanspruch 5, wobei das genannte erste Einsatzmetall mit dem genannten zweiten Einsatzmetall durch Eindringung während des Erwärmungsvorgangs vermengt wird, sodass eine Legierung des ersten und zweiten Metalls in einer Legierungsregion (701) an der Kontaktstelle beider Materialien (610) entsteht.

7. Das Verfahren nach den Patentansprüchen 1 bis 6, die um den folgenden Schritt ergänzt wurden:

Senken der Temperatur in der genannten Negativform auf eine Temperatur unterhalb der genannten ersten Temperatur, sodass sich das genannte erste Einsatzmaterial während eine Kühlphase (108) verfestigt.

8. Das Verfahren nach Patentanspruch 7, das um den folgenden Schritt ergänzt wurde:

Zuführen weiteren verflüssigten Materials in die genannte Negativform während der beschriebenen Kühlphase, während der sich das Material in der genannten Negativform zusammenzieht.

9. Das Verfahren nach den Patentansprüchen 1 bis 8, wobei die Erwärmungsphase unter einem Druck durchgeführt wird, der nicht dem üblichen Atmosphärendruck entspricht.

10. Das Verfahren nach den Patentansprüchen 7 bis 9, wobei die genannte Kühlphase unter einem Druck durchgeführt wird, der nicht dem üblichen Atmosphärendruck entspricht.

11. Das Verfahren nach den Patentansprüchen 1 bis 10, wobei die Temperatur in der genannten Form während der genannten Erwärmungsphase auf eine zweite Temperatur (1203) erhöht wird.

12. Das Verfahren nach Patentanspruch 11, wobei die genannte Trennvorrichtung schmilzt, wenn die Temperatur der genannten Negativform während der Erwärmungsphase auf die genannte zweite Temperatur erhöht wird.

13. Eine Vorrichtung zum Herstellen einer Verbundstoffkomponente aus einer Vielzahl unterschiedlicher Einsatzmaterialien in Pulverform, bestehend aus:

einer Negativform aus Keramik (102, 401, 601, 801, 901) mit einer ersten Öffnung (603, 804, 906) für eine erste Region (602, 802, 902) der Form sowie einer zweiten Öffnung (604, 805, 908) für eine zweite Region (605, 803, 904) der Form, wobei
die genannte erste Öffnung zum Einführen eines ersten Einsatzmaterials in Pulverform (104, 608, 806, 909) in diese erste Region der Form und die genannte zweite Öffnung zum Einführen eines zweiten Einsatzmaterials in Pulverform (105, 609, 807, 910) in die genannte zweite Region der Form vorgesehen ist; und
sich die genannte Negativform aus Keramik zum Erwärmen auf eine erste Temperatur (1106) während eines Erwärmungsvorgangs (106) eignet, **gekennzeichnet durch**:

eine Trennvorrichtung (808, 903) der genannten Negativform aus Keramik zwischen der genannten ersten und zweiten Region, wobei diese Trennvorrichtung ein Eindringen des genannten ersten Einsatzmaterials in das genannte zweite Einsatzmaterial verhindern soll, wenn diese in fester Form vorliegen, und schmilzt, um ein Eindringen des genannten ersten Einsatzmaterials in das genannte zweite Einsatzmaterial zu ermöglichen.

14. Die Vorrichtung aus Patentanspruch 13, wobei die Atmosphäre in die genannte Negativform aus Keramik eindringen kann.

Revendications

1. Une méthode de formation d'un composant composite à partir de plusieurs matières d'alimentation en poudre différentes, comprenant les étapes :

d'obtention d'un moule en céramique négatif (102, 401, 601, 801, 901) d'un composant définissant une première ouverture (603, 804, 906) associée à une première zone (602, 802, 902) du moule et une deuxième ouverture (604, 805, 908) associée à une deuxième zone (605, 803, 904) du moule ;
de déploiement d'une première matière d'alimentation en poudre (104, 608, 806, 909) dans

ladite première zone du moule négatif via la première ouverture et une deuxième matière d'alimentation en poudre (105, 609, 807, 910) dans ladite deuxième zone du moule négatif via la deuxième ouverture ;
de prévention de la dispersion de ladite première matière d'alimentation dans ladite deuxième matière d'alimentation en grâce à une partition (808, 903) séparant ladite première zone et ladite deuxième zone ;
d'augmentation de la température dans ledit moule négatif à une première température (1106) entraînant la fonte de ladite première matière d'alimentation lors d'une phase de chauffe (106) ; et
de fonte de ladite partition pour permettre la dispersion de ladite première matière d'alimentation dans ladite deuxième matière d'alimentation.

2. La méthode selon la revendication 1, ladite partition fondant lorsque la température dudit moule négatif est augmentée pour atteindre ladite première température durant ladite phase de chauffe.

3. La méthode selon la revendication 1 ou 2, ladite deuxième matière d'alimentation fondant pendant ladite phase de chauffe.

4. La méthode selon une quelconque des revendications 1 à 3, ladite première matière d'alimentation en poudre se dispersant dans ladite deuxième matière d'alimentation en poudre durant ladite phase de chauffe pour relier lesdites première et deuxième matières d'alimentation en poudre.

5. La méthode selon une quelconque des revendications 1 à 4, ladite première matière d'alimentation et ladite deuxième matière d'alimentation étant des métaux.

6. La méthode selon la revendication 5, ladite première alimentation métallique étant reliée à ladite deuxième alimentation métallique par la dispersion des particules durant ladite phase de chauffe pour allier lesdits premier et deuxième métaux sur une zone en alliage (701) à l'interface (610).

7. La méthode selon une quelconque des revendications 1 à 6, comprenant également l'étape de :

diminution de la température dans ledit moule négatif à une température inférieure à ladite première température, entraînant la solidification de ladite première matière d'alimentation pendant une phase de refroidissement (108).

8. La méthode selon la revendication 7, comprenant également l'étape de :

ajout des matières liquéfiées supplémentaires dans ledit moule négatif pendant ladite phase de refroidissement alors que le volume de la matière contenue dans ledit moule négatif se contracte.

9. La méthode selon une quelconque des revendications 1 à 8, ladite phase de chauffe se déroulant sous une pression non atmosphérique.

10. La méthode selon une quelconque des revendications 7 à 9, ladite phase de refroidissement se déroulant sous une pression non atmosphérique.

11. La méthode selon une quelconque des revendications 1 à 10, la température dans ledit moule étant augmentée à une deuxième température (1203) pendant ladite phase de chauffe.

12. La méthode selon la revendication 11, ladite partition ayant fondu lors de l'augmentation de la température dudit moule négatif à ladite deuxième température durant la phase de chauffe.

13. Un appareil pour former un composant en composite à partir de plusieurs matières d'alimentation en poudre différentes, comprenant :

un moule négatif en céramique (102, 401, 601, 801, 901) définissant une première ouverture (603, 804, 906) associée à une première zone (602, 802, 902) du moule et une deuxième ouverture (604, 805, 908) associée à une deuxième zone (605, 803, 904) du moule ; lorsque :

ladite première ouverture est configurée pour l'insertion d'une première matière d'alimentation en poudre (104, 608, 806, 909) dans ladite première zone du moule et ladite deuxième ouverture est configurée pour l'insertion d'une deuxième matière d'alimentation en poudre (105, 609, 807, 910) dans une deuxième zone du moule ; et
ledit moule négatif en céramique est conçu pour être chauffé à une première température (1106) pendant une phase de chauffe (106), **caractérisé en ce que** :

ledit moule négatif en céramique comprend également une partition (808, 903) séparant lesdites première et deuxième zones, ladite partition étant configurée pour prévenir la dispersion de ladite première matière d'alimentation dans ladite deuxième matière d'alimentation lorsqu'elle est sous forme solide et également configurée pour fondre et permettre la dispersion de ladite première matière d'alimentation dans ladite deuxième matière d'alimentation.

14. L'appareil selon la revendication 13, ledit moule négatif en céramique étant configuré pour être perméable à l'atmosphère utilisée.

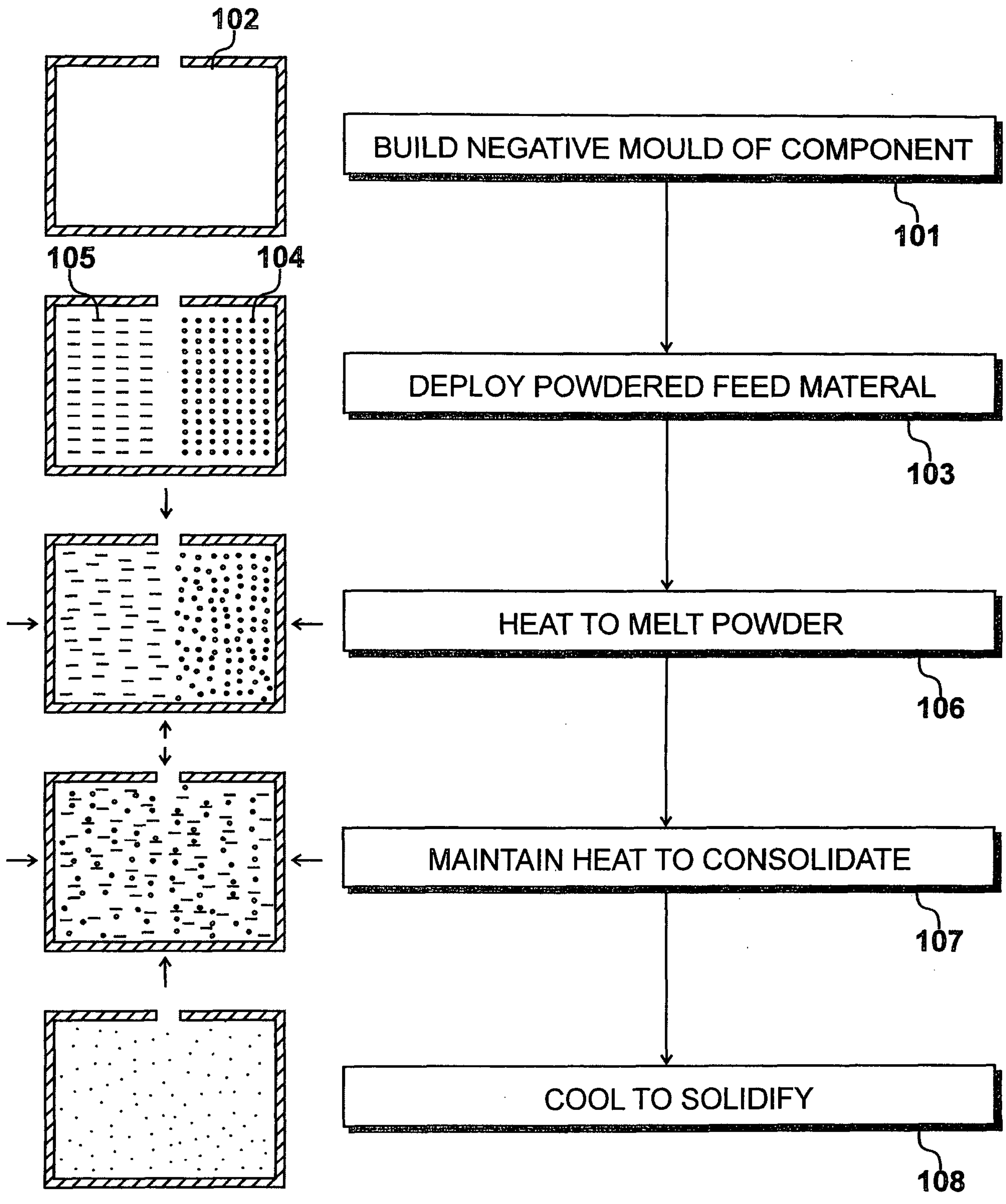

102
105
104
BUILD NEGATIVE MOULD OF COMPONENT
101
DEPLOY POWDERED FEED MATERAL
103
HEAT TO MELT POWDER
106
MAINTAIN HEAT TO CONSOLIDATE
107
COOL TO SOLIDIFY
108

Fig. 1

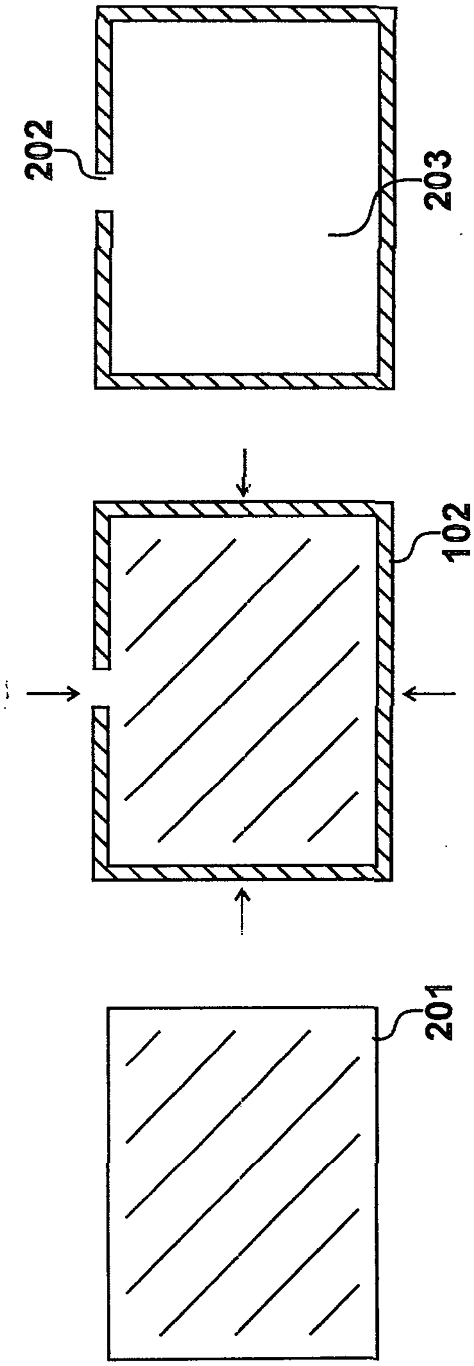


Fig. 2

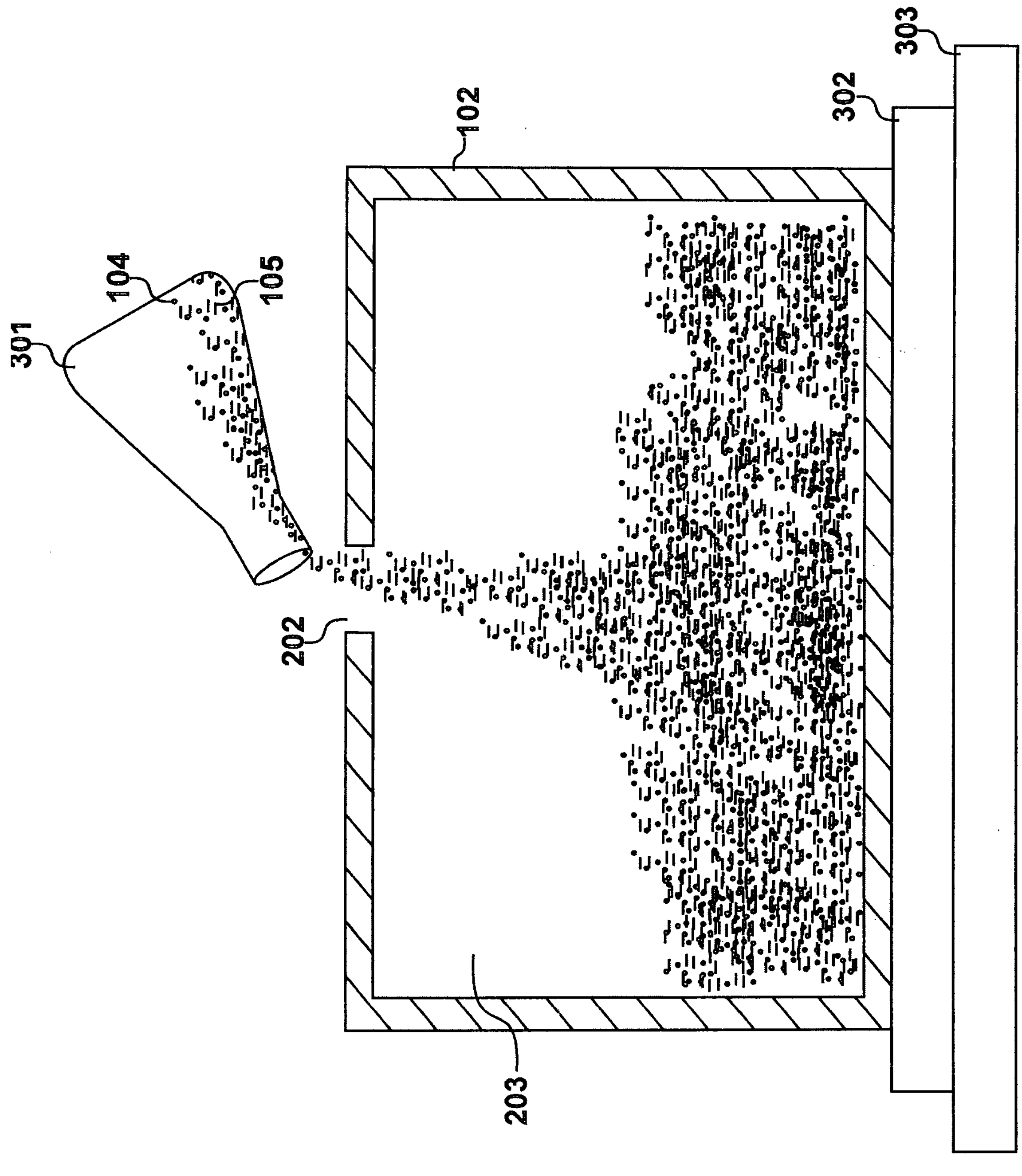


Fig. 3

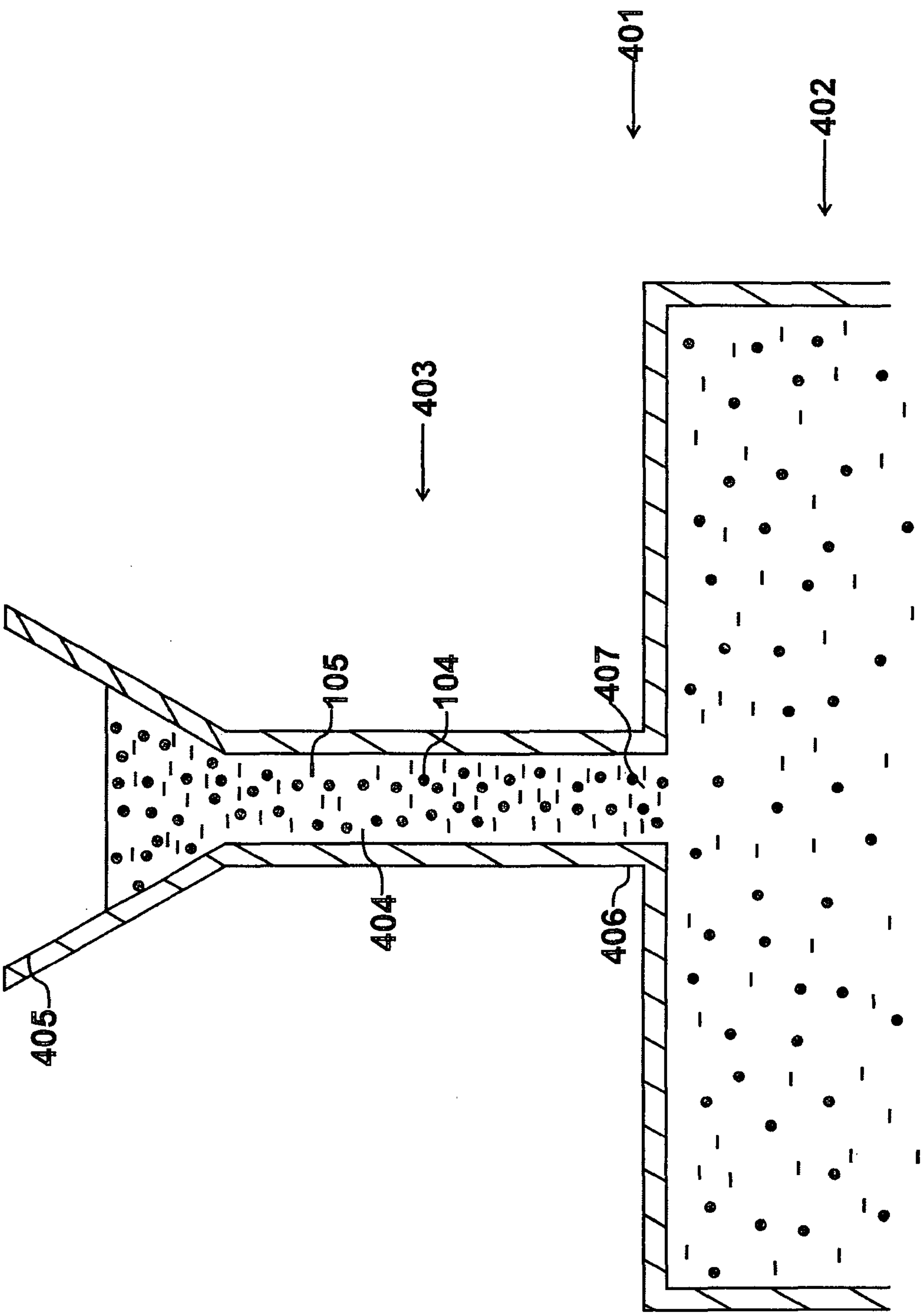


Fig. 4

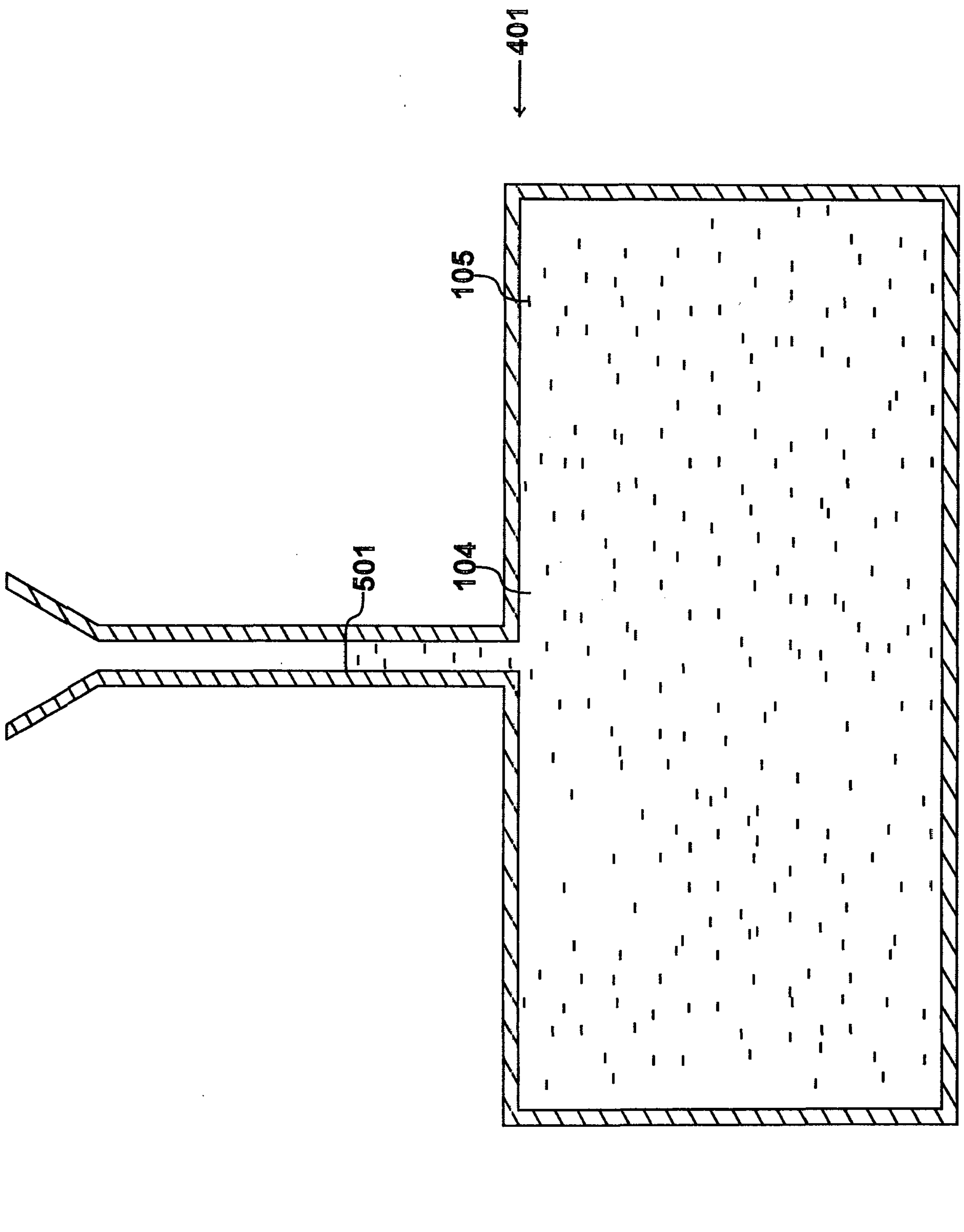


Fig. 5

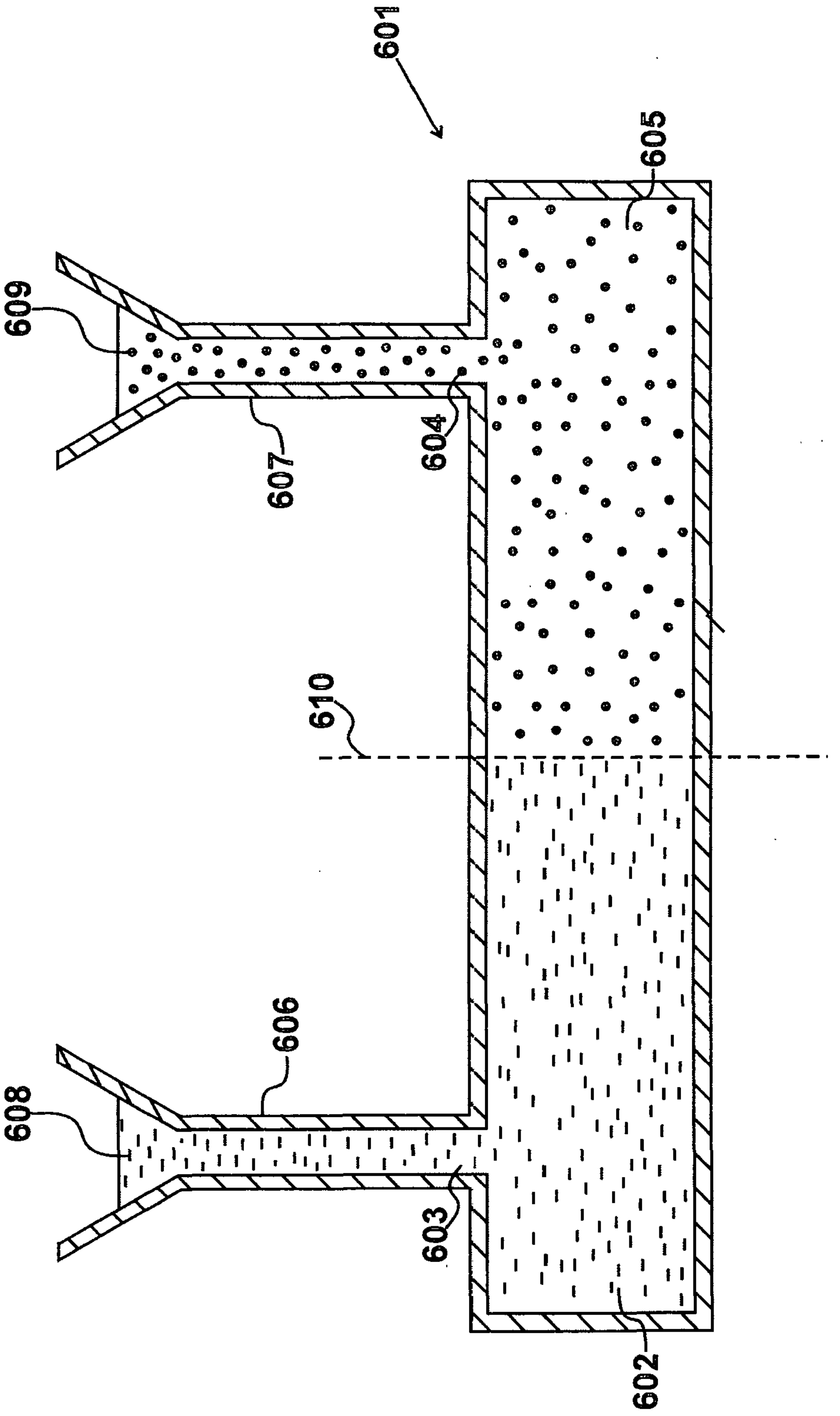


Fig. 6

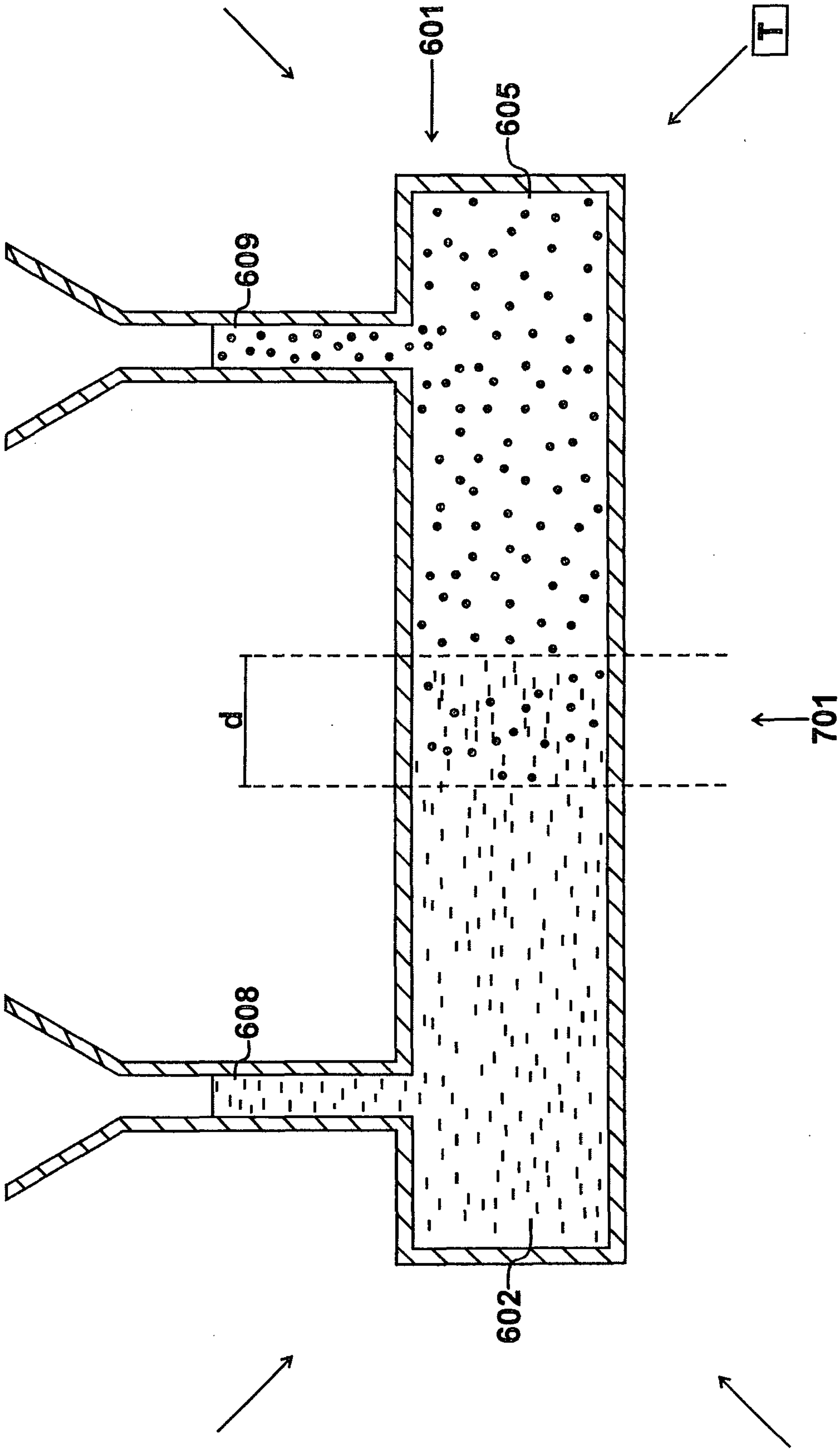


Fig. 7

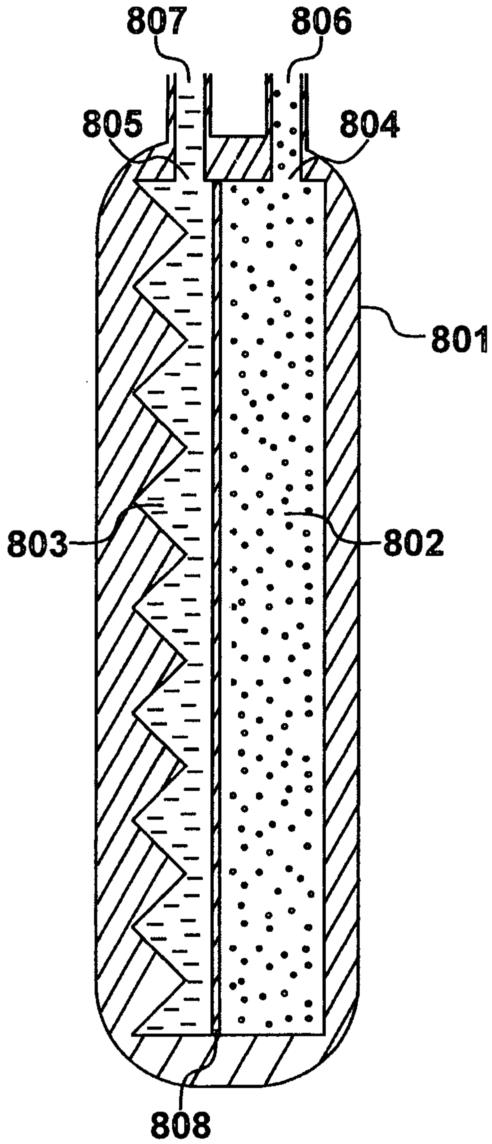


Fig. 8

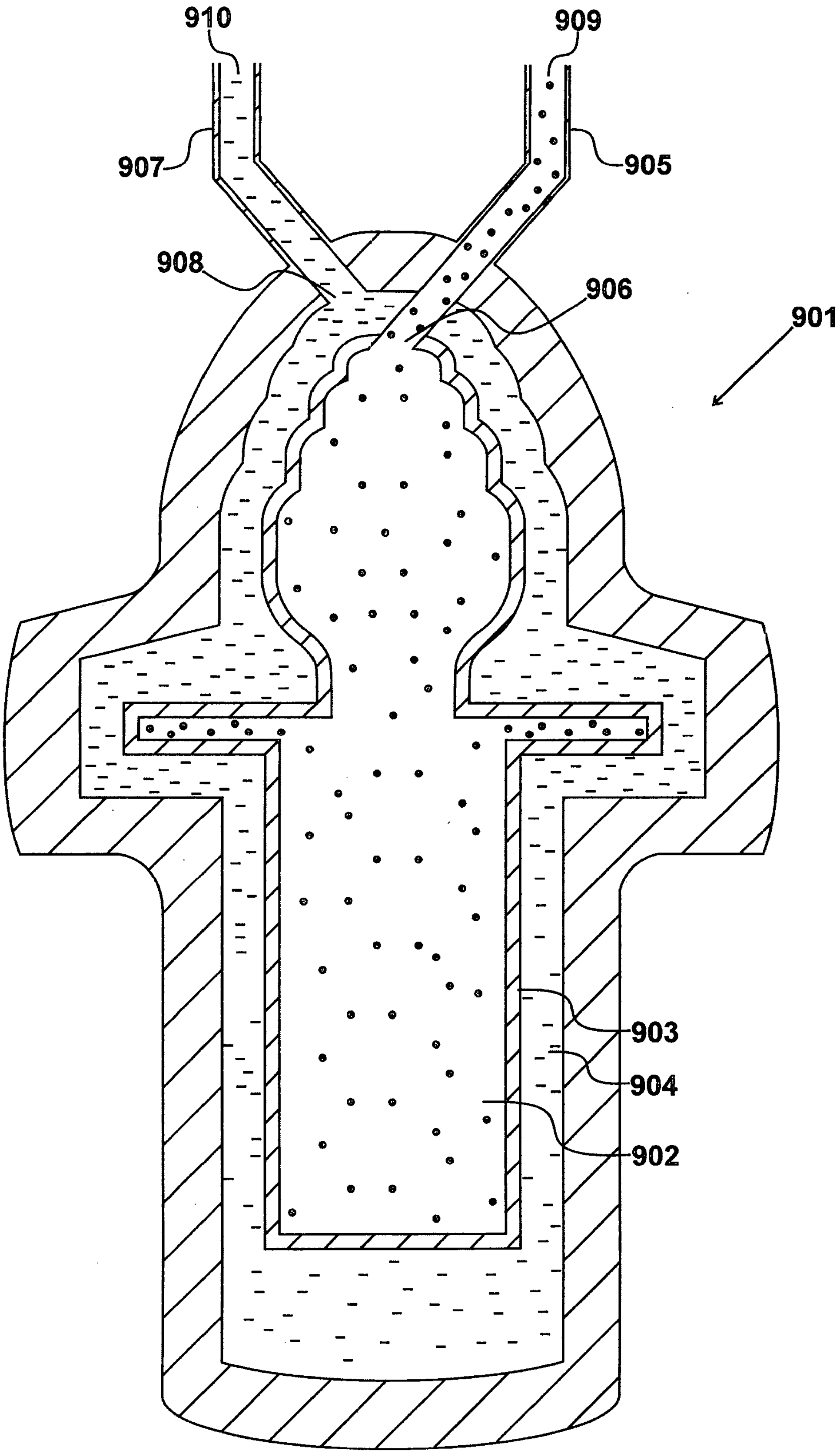
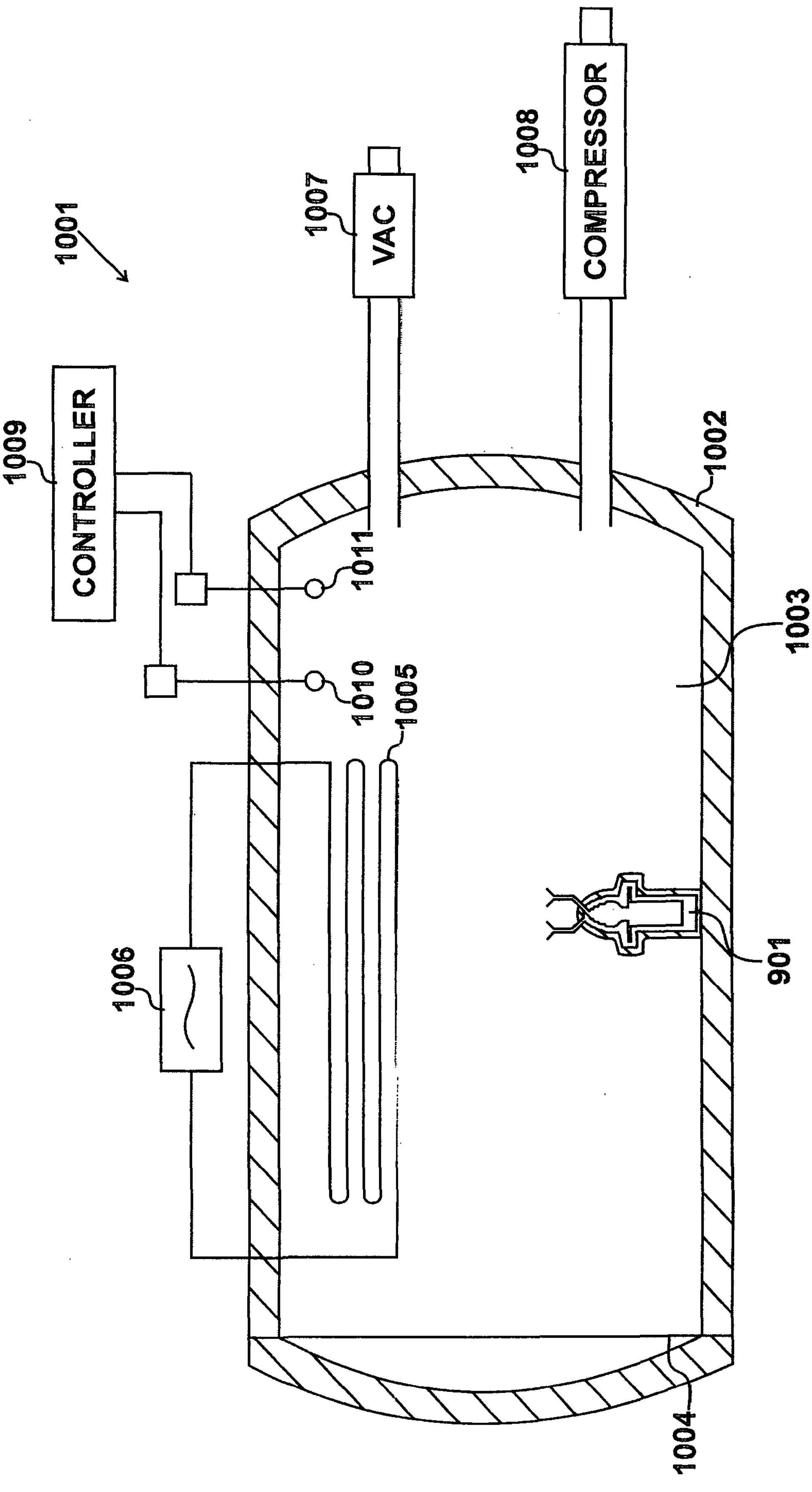


Fig. 9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1007
VAC
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COMPRESSOR
1002
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1003
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1005
1006
901
1004

Fig. 10

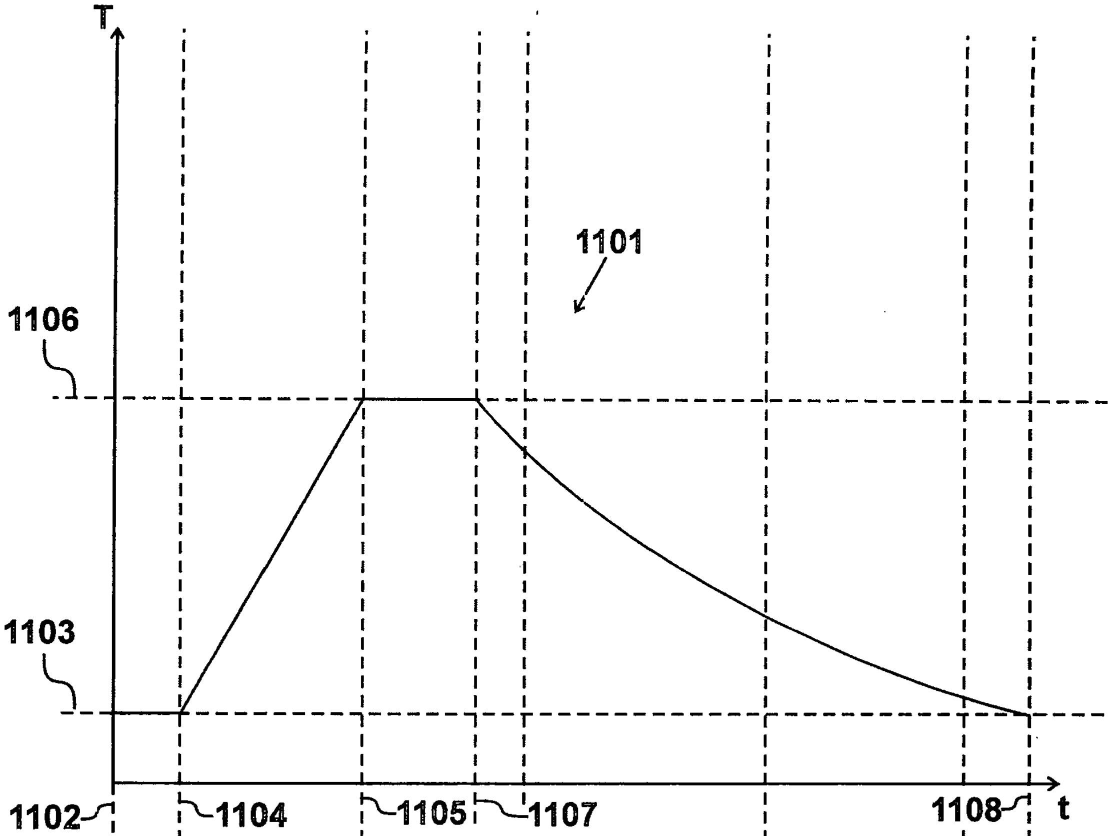
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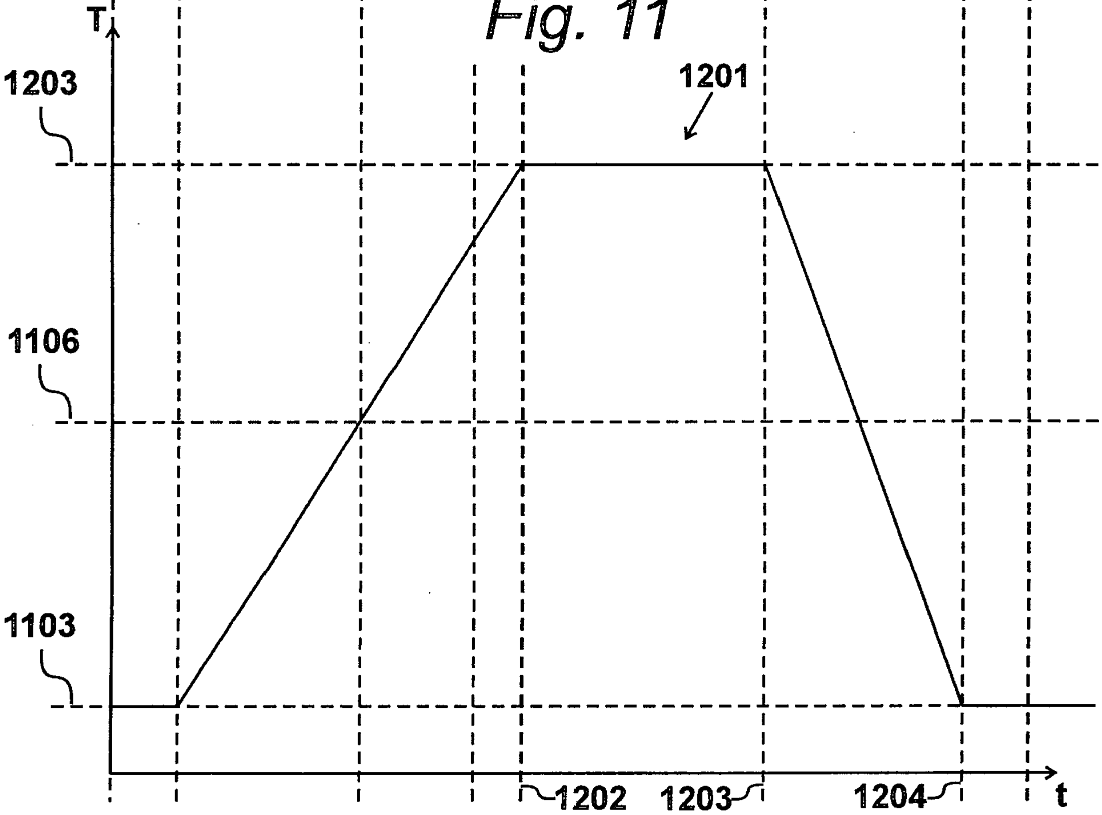
Fig. 11


T
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1204
t

Fig. 12

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 2013294901 A1, Mironets **[0007]**
- EP 1724438 A2 **[0007]**
- EP 0072175 A1, Mowill **[0008]**