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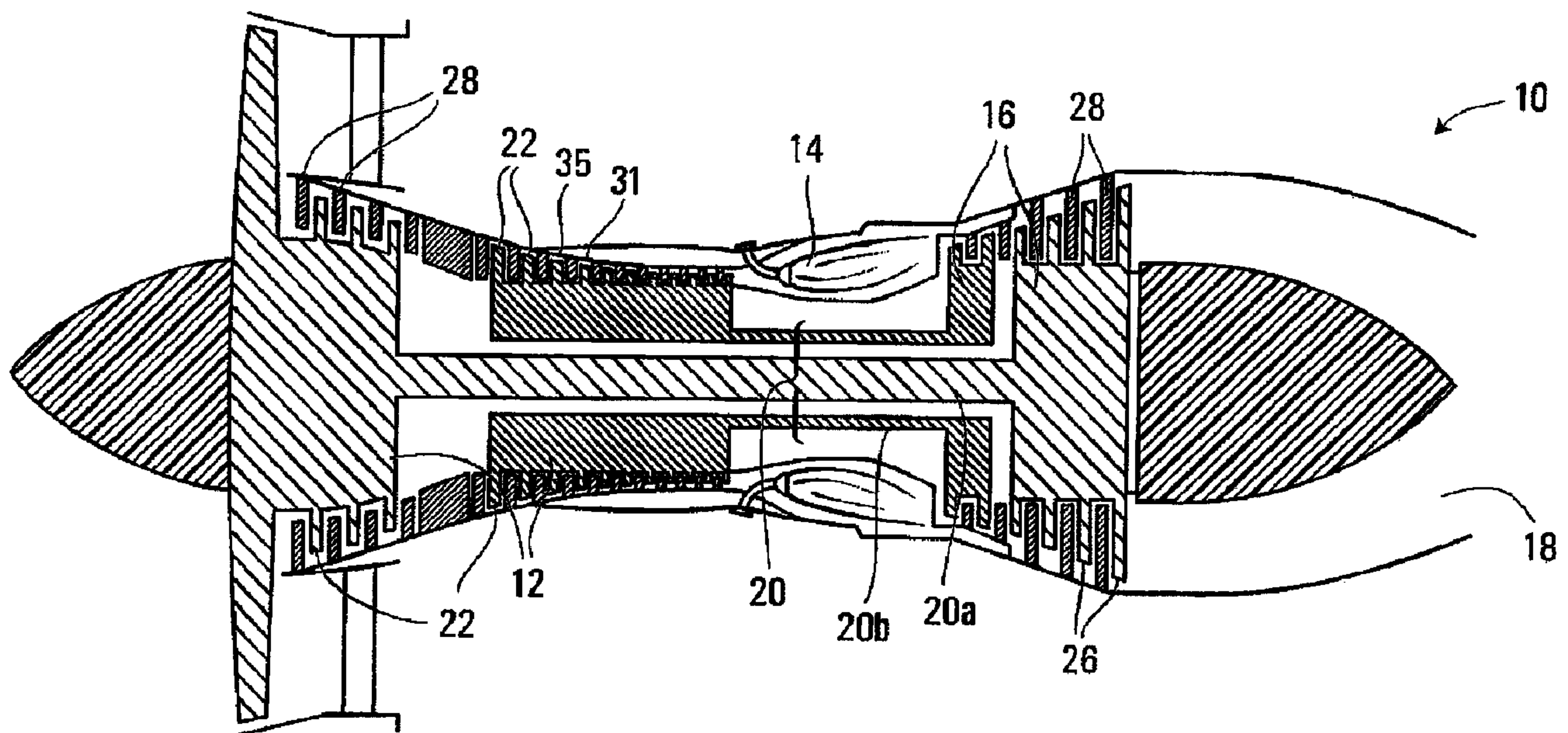
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(54) Titre : PROCEDE DE FABBRICATION D'ELEMENTS STATIQUES POUR TURBINES A GAZ

(54) Title: A PROCESS FOR PRODUCING STATIC COMPONENTS FOR A GAS TURBINE ENGINE



(57) Abrégé/Abstract:

Static components for a gas turbine engine formed from a metal injection molding process. The static components are made from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and have a density less than 99% of a theoretical possible density for the alloy.



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ABSTRACT

Static components for a gas turbine engine formed from a metal injection molding process. The static components are made from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and have a density less than 99% of a theoretical possible density for the alloy.

TITLE: A PROCESS FOR PRODUCING STATIC COMPONENTS FOR A GAS TURBINE ENGINE

FIELD OF THE INVENTION

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[001] The present invention relates generally to the field of gas turbine engines, and more particularly to static components of a gas turbine engine formed from a metal injection process that imparts certain material characteristics.

10 **BACKGROUND OF THE INVENTION**

[002] In the aerospace industry, there is a constant effort to reduce manufacturing costs while maintaining the quality and safety standards associated with building commercial and military aircraft. Some of the most expensive and complicated parts of an aircraft are found in the gas turbine engines that provide the thrust necessary for flight.

[003] Gas turbine engines contain both static and rotating parts. In general, many of the parts that go into gas turbine engines are made from raw pieces of material that are machined into the desired shape. There are many deficiencies associated with the manner in which turbine components are manufactured. One deficiency is that the components are made from expensive raw materials, and machining these expensive raw materials results in significant waste of both costs and useful raw material. In addition, many of these expensive materials are very difficult to work with, which results in increased costs for manufacturing the components. For example, Rhenium metal, which is one of the materials that is used for gas turbine engine components cannot be worked at room temperature. Thus, production of components made out of this material is both difficult and expensive.

30 [004] A further deficiency is that many materials that could be desirable for use in a gas turbine engine cannot be processed using existing manufacturing and production techniques. For example, many metals, metal alloys, ceramics and composites cannot

be processed via machining. Likewise, many components having obscure shapes and configurations can also not be manufactured using traditional techniques.

[005] In light of the above, it can be seen that there is a need in aerospace industry to lower the effective cost of manufacturing quality, high density, fatigue resistant parts, including parts destined for the hot section of a gas turbine engine (GTE), and for reducing at least in part, the deficiencies associated with existing manufacturing techniques. There is also the need for a technique that provides increased manufacturing freedom for new materials, and shapes of components.

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SUMMARY OF THE INVENTION

[006] In accordance with a first broad aspect, the present invention provides a static component for a gas turbine engine made from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy. The component has a density less than 99% of a theoretical possible density for the alloy, and is made by a metal injection molding process.

[007] In accordance with a second broad aspect, the present invention provides a static component for a gas turbine engine. The precursor is made from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy. The precursor has a density less than 99% of a theoretical possible density for the alloy, and is made by a metal injection molding process.

[008] In accordance with a third broad aspect, the present invention provides a process for making a static component for a gas turbine engine. The process comprises preparing a fluid feedstock including metallic powder selected from the group consisting Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and binder material, injecting the feedstock into a mold having cavity approximating the shape of the component to form a green part, debinding the green part to provide a debound part and sintering the debound part. The preparing, injecting,

debinding and sintering is performed at process conditions such that said component has a density less than 99% of a theoretical possible density for the alloy.

5 [009] In accordance with a fourth broad aspect, the present invention provides a process for making a static component for a gas turbine engine as described above, further comprising performing one or more process step on said precursor to yield a component that has a higher density than said precursor.

10 [010] In accordance with a fifth broad aspect, the present invention provides a static component for a gas turbine engine. The component being made from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy from a metal injection molding process. The components have pores throughout, the pores having an average sphericity greater than 0.5.

15 [011] In accordance with a sixth broad aspect, the present invention provides a static component for a gas turbine engine. The precursor being made from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and having pores throughout. The pores having an average sphericity greater than 0.5. The precursor is made by a metal injection molding process.

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[012] In accordance with a seventh broad aspect, the present invention provides a static component for a gas turbine engine. The process comprises preparing a fluid feedstock including metallic powder selected from the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and binder material, 25 injecting the feedstock into a mold having a cavity approximating the shape of the component to form a green part, debinding the green part to provide a debound part and sintering the debound part to yield the component. The preparing, injecting, debinding and sintering being performed at process conditions such that the component has pores throughout, the pores having an average sphericity greater than 0.5.

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[013] In accordance with an eighth broad aspect, the present invention provides a static component for a gas turbine engine. The component being made from an alloy in the

group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and having pores throughout. The pores have an average pore size diameter of less than 10 microns. The component being made by a metal injection molding process.

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[014] In accordance with a ninth broad aspect, the present invention provides a static component for a gas turbine engine. The precursor is made from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and has pores throughout. The pores have an average pore size diameter of less than 10 microns. The component being made by a metal injection molding process.

[015] In accordance with a tenth broad aspect, the present invention provides a static component for a gas turbine engine. The process comprising preparing a fluid feedstock including metallic powder selected from the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and binder material, injecting the feedstock into a mold having a cavity approximating the shape of the component to form a green part, debinding the green part to provide a debound part, sintering the debound part to yield the component. The preparing, injecting, debinding and sintering being performed at process conditions such that the collar has pores throughout. The pores have an average pore size diameter of less than 10 microns.

[016] In accordance with an eleventh broad aspect, the present invention provides a static component for a gas turbine engine as described above, further comprising performing one or more process step on said precursor to yield a component that has a higher density than said precursor.

[017] In accordance with a twelfth broad aspect, the present invention provides a set of static components for a gas turbine engine. Each component in the set being made from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy. The set of components being made by a metal injection molding process from a common mold having a component-shaped cavity, each component in the set of components is produced during a different molding cycle

of the common mold. The set of components have dimensional tolerances variation of less than 0.5% between components in said set.

5 [018] In accordance with a thirteenth broad aspect, the present invention provides a process for making a set of static components for a gas turbine engine. The process comprising preparing a fluid feedstock including metallic powder selected from the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and binder material, injecting the feedstock into a mold having cavity approximating the shape of the component to form a green part, debinding the
10 green part to provide a debound part, sintering the debound part to yield the component. The preparing, injecting, debinding and sintering being performed at process conditions such that the component has pores throughout. The pores having an average pore size diameter of less than 10 microns.

15 [019] In accordance with a fourteenth broad aspect, the present invention provides a process for making a set of static components for a gas turbine engine. The process comprises preparing a fluid feedstock including metallic powder selected from the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and binder material, injecting the feedstock into a mold having a
20 component-shaped cavity to form a green part, debinding the green part to provide a debound part, sintering the debound part to yield a component of the set and repeating the injecting, debinding and sintering a number of times sufficient to make all the components of the set of components, wherein the preparing, injecting, debinding and sintering are performed at process conditions such that the set of components has a
25 dimensional tolerance variation of less than 0.5% between components in said set.

[020] In accordance with a fourteenth broad aspect, the present invention provides a gas turbine engine including a hot section in which is mounted a rotating assembly and a plurality of static components about which the rotating assembly turns during operation
30 of the gas turbine engine. At least one of the static components are made by metal injection molding from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and have pores throughout

which donate to the at least one static component a density less than 100% of a theoretical possible density for the alloy.

5 [021] These and other aspects and features of the present invention will now become apparent to those of ordinary skill in the art upon review of the following description of specific embodiments of the invention and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

10 [022] In the accompanying drawings:

[023] Figure 1 shows a cross-sectional diagram of a gas turbine engine in accordance with a non-limiting example of implementation of the present invention;

15 [024] Figure 2a shows a side view of a stator vane having a non-limiting shape that can be manufactured in accordance with the present invention;

[025] Figure 2b shows a cross sectional view of the stator vane of Figure 2;

20 [026] Figure 3 shows a perspective view of a fuel swirler having a non-limiting shape that can be manufactured in accordance with the present invention;

[027] Figure 4 shows a cross sectional view of a floating collar having a non-limiting shape that can be manufactured in accordance with the present invention;

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[028] Figure 5 shows a front view of a heat shield having a non-limiting shape that can be manufactured in accordance with the present invention;

30 [029] Figure 6 shows a side view of a shroud segment having a non-limiting shape that can be manufactured in accordance with the present invention;

[030] Figure 7 shows a flow diagram of a non-limiting process used for metal injection molding in accordance with the present invention;

5 [031] Figure 8 shows a non-limiting example of a machine for performing the mixing and injection molding steps of the metal injection molding process shown in Figure 7; and

[032] Figure 9 shows an optical micrograph of a sintered component manufactured in accordance with the present invention.

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[033] Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

DETAILED DESCRIPTION

[034] As will be described in detail below, the present invention relates generally to static components for gas turbine engines that are produced using a metal injection molding process. For the sake of simplicity, the present invention will be described in the context of gas turbine engines used for powering aircraft. However, it should be understood that the components and processes described herein are equally applicable to gas turbine engines used for other applications, such as electrical power generation, among other possibilities.

Gas turbine engines

[035] Shown in Figure 1 is a non-limiting example of a gas turbine engine 10 suitable for use in powering a subsonic aircraft. Gas turbine engines, such as the one shown in Figure 1, generally have three major operating sections; the compressors 12, the combustion chamber 14, and the turbines 16. The compressors 12 include a plurality of fan blades 22, and the turbines 16, which are located downstream from the compressors 12, include a plurality of turbine blades 26. As shown, both the turbine blades 26 and the compressor fan blades 22 are connected to a common shaft 20. During operation, air enters the gas turbine engine 10 and is compressed by the compressors 12. This compressed air is then mixed with fuel and ignited in the combustion chamber 14, resulting in gasses that exit the combustion chamber 14 and flow over the turbine blades 26, thus causing the shaft 20 to rotate. The rotation of the shaft 20, in turn, powers the compressor 12. Finally, the gasses that have flowed over the turbine blades 26 pass through a nozzle 18, which generates additional thrust by accelerating the hot exhaust gasses as they expand back to atmospheric pressure. Energy can be extracted from the gas turbine engine in the form of shaft power, compressed air and thrust for powering the aircraft.

[036] Contained within the gas turbine engine 10 are a hot section, a plurality of static components and a rotating assembly that rotates in relation to the static components during operation of the gas turbine engine 10. For the purposes of the present invention, “the hot section” refers to the sections and components of a gas turbine engine that are

exposed to hot gases, such as the combustion chamber, the high pressure guide vanes, the high pressure turbine, the high pressure turbine shroud, the housing assembly, the low pressure turbine guide vanes, the low pressure turbines and the exhaust case, among other possibilities. In general hot sections of an engine are exposed to
5 temperatures of greater than 300°C. It should however, be appreciated that this temperature may vary depending on the size of the gas turbine engine. For example, typical gas turbine engines will have a hot section that is exposed to temperatures of between 800-1400°C.

10 [037] The rotating assembly generally comprises one or more rotating shafts 20 as well as a plurality of rotating turbine blades 26 and compressor fan blades 22. In the non-limiting embodiment shown in Figure 1, the gas turbine engine 10 includes two concentric rotating shafts; namely shaft 20a and shaft 20b. The outermost turbine blades 26 and compressor fan blades 22 are connected to rotating shaft 20a, and the innermost
15 turbine blades 26 and compressor fan blades 22 are connected to rotating shaft 20b.

[038] The gas turbine engine 10 further includes a plurality of static components that are either not designed to move during operation of the engine or that are subject to motion which induces forces in the part that may cause it to break (such as an actuator
20 arm, for example). For the purposes of the present application, the static components located within the gas turbine engine 10 are the parts that do not rotate above 100 RPM. Such static components include stator vanes 28 located between the compressor fan blades 22 and the turbine blades 26, a fuel swirler 30, shown in Figure 3, for introducing fuel into the combustion chamber 14, a floating collar 32, shown in Figure
25 4, for coupling the fuel swirler to the combustion chamber 14, a heat shield 34, shown in Figure 5, located at the head area of the combustion chamber 14 and a shroud segment 35 that surrounds the stator vanes.

[039] In accordance with the present invention, the above listed static components,
30 namely the stator vanes 28, the fuel swirler 30, the floating collar 32, the heat shield 34 and the shroud segment 35 are produced via a metal injection molding process which will be described in more detail below. The process conditions for the metal injection

molding procedure are controlled so as to impart to the static components certain material characteristics relating to density, pore sphericity and pore size distribution.

Metal Injection Molding

5 [040] In accordance with the present invention, each of the static components is produced via a metal injection molding process (otherwise known as powder injection molding process), which gives the components certain material characteristics relating to density, pore size and pore sphericity. Metal injection molding is a relatively low cost manufacturing process that can produce complex net-shape components from metals,
10 metal alloys, ceramics, cemented carbides and cermets (ceramic-metal composites), among other possibilities.

[041] Shown in Figure 7 is a non-limiting flow diagram of the four main steps in a metal injection molding process. The first step 100 is to form a feedstock material by
15 mixing together a powder of the base material/alloy from which the component is to be manufactured, and a binder. The powder can be any fine metallic powder, alloy powder, ceramic powder or carbide powder, depending on the desired material for the final part. As indicated above, some non-limiting examples of alloys that can be used for the stator vanes, fuel swirlers, floating collars and heat shields of a gas turbine include Inconel
20 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloys. In general, it is preferable to use alloys that have at least 60% nickel, cobalt or iron, or a combination thereof. In addition, the powder is preferably made of spherical particles having a diameter of less than 25 μ m. It should, however, be appreciated that a powder having particles of any shape and size can be used without departing from the spirit of
25 the invention.

[042] Although certain examples of alloys are identified above, it should be appreciated that any alloy having desired material characteristics (i.e. mechanical, chemical and physical characteristics) can be used without departing from the spirit of the invention.
30 For example, the alloy from which the part is made may be selected on the basis of desired characteristics relating to oxidation resistance, corrosion resistance and material

strength. Corrosion resistance and oxidation resistance can be measured in terms of mm/yr under certain conditions.

[043] The binder that is mixed with the metal alloy powder may be any polymeric
5 binder, and may include a mixture of polymers, such as waxes, dispersants and
surfactants. Typical polymers include polyethylene, polyethylene glycol, polymethyl
methacrylate, polypropylene. A typical wax that is used is a paraffin wax. It should be
appreciated that any type of binder suitable for the intended purpose can be used
without departing from the spirit of the invention. The manner in which the appropriate
10 powder and binder are chosen, as well as the percentage of each that is used to form the
feedstock, are known to those of skill in the art, and as such will not be described in
more detail herein.

[044] During the mixing step 100, pre-calculated proportions of the powder and binder
15 are mixed together to obtain a homogeneous and predictable feedstock with desirable
rheological behaviour. In accordance with a non-limiting example, the powder and
binder are hot mixed together using a continuous or batch mixer, and are then cooled
and granulated to form the feedstock material to be supplied to an injection molding
machine. The powder and binder can be mixed together under isothermal conditions to
20 form a homogenous suspension. In accordance with a non-limiting example, the mixing
temperature is maintained below 90°C. However the process conditions used to produce
the appropriate temperature and consistency of feedstock are known in the art, and will
not be described in more detail herein.

25 [045] Once the feedstock has been mixed, the process proceeds to step 110, at which
point the feedstock is injected into a suitable mold for being molded into the shape of
the desired part. In accordance with a non-limiting embodiment, the feedstock is
supplied to the mold using low-pressure injection conditions of less than 100psi. In
order to ensure proper filling of the mold under these conditions, the rheological
30 parameters of the feedstock are adjusted in accordance with the molding parameters
(i.e. the injection pressure, injection duration, mold material and temperature of the
mixture). For example, the feedstock is generally prepared at step 100 such that it has at

least one of its rate of shear, elasticity, plasticity, viscosity and behaviour in relation to temperature and pressure adapted for use with the molding apparatus.

[046] Shown in Figure 8 is a non-limiting example of a machine 60 suitable for use in the mixing and molding steps of the metal injection molding process. The machine 60 includes a feedstock cartridge 62 for holding the feedstock in a solid state prior to use. Located below the feedstock cartridge 62 is a feedstock supply screw 64 for transferring the feedstock in its solid state through the feedstock transfer chamber 68 into the mixing chamber 66. The feedstock transfer chamber 68 transfers the feedstock into the mixing chamber 66 under vacuum. Once in the mixing chamber 66, the feedstock is heated and mixed so as to form the feedstock that is supplied to the injection chamber 70. The volume of feedstock within the mixing chamber 66 is kept at a constant fill level by synchronising the addition of the feedstock from the cartridge 62 and the volume injected into the injection molds in the injection chamber 70.

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[047] Located below the mixing chamber 66 is an injection chamber 70 into which a specific volume of the feedstock is injected into a mold. The mold includes a cavity in the shape of the component being formed, whether that is a stator vane, a fuel swirler, a floating collar, a heat shield, or a shroud segment among other possible components. In accordance with a non-limiting example, the injection chamber 70 is kept at the same temperature as the mixing chamber 66, and the injection pressure is typically less than 700 KPa. This pressure is maintained while the part is cooling to prevent void or crack formation due to contraction. The molding time typically takes less than 30 seconds.

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[048] The mold can be made from steel, aluminum, bronze, brass or any other metallic material or from polymeric resins such as epoxy, or other thermoplastics, for example. The mold may or may not include another material to facilitate the heat transfer, the shrinkage or any other molding-related aspect. The molds can be hand-made using techniques from the jewelry field or from stereolithography. These mold manufacturing techniques allow reducing development-related and production costs, especially when manufacturing small volumes of components.

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[049] The mold is operative for shaping the mixed feedstock into a defined shape, so as to form what is called a “green part”. Once the green part has been formed, meaning that the feedstock has acquired the desired shape and has been removed from the mold, the process proceeds to step 120, which is the debinding step. The purpose of the debinding step 120 is to remove the binder from the powder material, without distorting the molded shape of the green part. Thermal debinding is the most common technique used to debind the part, but any debinding technique can be used without departing from the spirit of the invention. For example, the debinding can be done using solvents, or even water in the case where water soluble polymers, such as polyethylene glycol are used as binders.

[050] In the case of thermal debinding, the molded part is heated in an oven under controlled conditions, such that part of the binder is eliminated at a lower temperature, while the backbone polymer of the binder maintains the powder particles of the molded part in place. This first stage of the debinding process forms a porous network, which eventually helps in the evacuation of the degradation residues from the backbone polymer. It also reduces the internal pressure that could deform the part. The backbone polymer is then thermally removed. Even in the cases where a portion of the binder is removed via solvent, the backbone polymer is generally still thermally removed in a second stage procedure. In some cases, this second stage of the debinding process is performed during the sintering stage, which will be described below, in order to avoid any damage to the debound part.

[051] As shown in Figure 7, the final step in the metal injection molding process is the sintering step 130. During the sintering step 130 the debound part is heated to a temperature that is lower, but close to, the melting temperature of the powder material for bonding the powder particles together. The temperature, duration of heat application and furnace atmosphere are controlled to ensure that the sintered component has the required densification and material properties desired. The sintering step densifies the component by removing the voids left behind from the debinding step 120. In many cases the sintering step can result in the part shrinking slightly. As such, the mold that is used during the molding stage 110 is designed to compensate for the final shrinkage

that occurs during sintering. The typical shrinkage of a part is between 10%-18% depending on the solid loading of the feedstock and the level of densification achieved during sintering.

5 [052] Once the metal powder has been processed in the manner described above, the sintered component will have a certain grain size. In accordance with a non-limiting example, the grain size for the Inconel 625 alloy, once processed, is typically under 75 microns. When using the ASTM E112 standard for grain size characterisation, the grain size for static components formed in connection with the present invention are
10 typically, ASTM #4 to ASTM #7. In general, the smaller the grain size, the better the mechanical properties of the end component.

[053] In some circumstances, the component formed after the sintering step 130 is a precursor to the final component. Once the precursor has been produced, one or more
15 additional process steps can be performed on the precursor to yield the final component. For example, the additional process steps may cause the final component to have a higher density than the precursor that was formed by the metal injection molding process. In accordance with a non-limiting example of implementation, the additional process step could be a hot isostatic pressing operation (HIP). HIP is a process in which
20 the porosity level of the part can be reduced thus further densifying the part, sometimes up to 100%.

[054] In order to perform a hot isostatic pressing operation, the parts to be treated are placed in a sealed chamber, which is heated to between 800-1000°C. Once heated, the
25 chamber is then pressurised to a pressure above 150 MPa. When performing the pressurization operation on sintered parts, the pores within the parts should be closed, such that gas pressure does not build up in the pores, which could impede deformation to higher density levels. According to Powder Metallurgy and Particulate Materials Processing (German R.M., MPIF, 2005, p.366), for a sintered part having a density of
30 96%, 100% of the pores are closed. For a sintered part having a density of 92%, approximately 50% of the pores are closed. As such, for sintered parts that have a

density of at least 95%, 100% of the pores are closed and non-communicative, meaning that they do not overlap other pores.

5 [055] Other processes that can be performed on the precursor include finishing machining, different types of surface treatments and/or heat treating.

10 [056] The metal injection molding process described above has many advantages. For example, forming components via metal injection molding can result in cost savings given that there is very little wastage of expensive raw materials. Further advantages include increased design and material flexibility, high-speed production and good mechanical properties. In general, the mechanical, physical and chemical properties of the static components formed using the metal injection molding technique described above are comparable to those of wrought material. In addition, components formed from the metal injection molding process require minimal secondary and assembly
15 operations in order to complete the component being manufactured.

[057] The metal injection process is also able to produce components that are consistently able to meet strict tolerance requirements. In the case of the floating collar, the stator vanes, the fuel swirler and the shroud segment, the tolerance for each
20 dimension can be 0.5% or lower. As such, for a 1 inch dimension, there is a variation of ± 0.0025 of an inch. Likewise, for a dimension of $\frac{1}{2}$ an inch, there is a variation of ± 0.001 of an inch. In certain circumstances, the metal injection process is able to achieve tolerances lower than 0.3%. Although the heat shield is a bigger part, in certain circumstances, the tolerances can also be lower than 0.5%.

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[058] A further advantage of the metal injection molding process is that it is able to produce a set of components from a common injection mold, such that there is a relatively small variation in dimensional tolerance between each component in a given production lot. Each component in the set of components is produced during a different
30 molding cycle using a common mold. As described above, the set of components may be a set of stator vanes, a set of fuel swirlers, a set of floating collars, a set of heat shields or a set of shroud segments among other possibilities. In accordance with a non-

limiting example of implementation, the process conditions used during the mixing, injecting, debinding and sintering steps are such that each component in the set of components has a relatively consistent variation in dimensional tolerance. In addition, a consistent variation in dimensional tolerances in components from production lot to production lot is also achieved. In accordance with a non-limiting example, the variation in dimensional tolerance is typically in the range of 0.5%. For components having dimensions in the range of from 1/4" to 3", this process can achieve 1 σ results, meaning that approximately 68% of the components in the set of components achieve a dimensional tolerance in the range of 0.5%. These results are even better for components having smaller dimensions. More specifically, for components having dimensions of 1/8" or less, the metal injection molding process described above can achieve 6 σ results, meaning that 99.9997% of the components have a dimensional tolerance in the range of 0.5%.

[059] In general, the set of components can include anywhere from 200-800 parts, while still maintaining the variation in dimensional tolerances as described above. For example, a production lot of heat shields may include 225 parts, a production lot of stator vanes may include 500 parts and a production lot of floating collars, fuel swirlers and shroud components may include 800 components.

In order to measure the dimensional tolerances between components in a production lot, or between components from production lot to production lot, different techniques can be used. Some non-limiting examples of different techniques include CMM testing, and testing using micrometers, callipers and no/no-go gauges. In accordance with a specific non-limiting example, a calliper is used to measure each dimension specified on an engineering drawing. This measurement verification is performed on each part in the production lot.

[060] As previously mentioned, using the above described metal injection molding technique provides either the final components, or the precursors to the final components with certain material characteristics in terms of density, pore size and pore sphericity. Each of these characteristics will now be described in more detail.

Sphericity

The debinding step that is performed during the metal injection molding process described above causes pores to be created in the material from which the component is formed. In this manner, the components produced from the metal injection process are porous components, having a density less than the theoretical density possible in the case where the material does not contain pores. Shown in Figure 9 is an optical micrograph of a sintered component having pores contained throughout. In the Micrograph of Figure 9, a combination of pores and second phase particles are shown in black. Ideally, the pores and second phase particles are substantially spherical in shape. The more spherical the pores, the less likely they are to propagate cracks or weakness than if they had a more jagged shape.

[061] In accordance with the present invention, the sphericity of the pores is calculated according to the following formula:

$$S=(4\cdot\pi\cdot A)/P^2$$

Where: A = area of the pore

P = perimeter of the pore

[062] The following is a non-limiting example of a method for measuring the sphericity of the pores within a static component formed from the metal injection molding process described above. The method involves using a scanning electron microscope, or optical microscope, to capture micrograph images of the microstructure of the component and then analysing the images using a software program, such as Clémex Vision, to isolate details in the microstructure of the component.

[063] The following is a detailed process used for measuring the sphericity of the pores within a static component:

Step 1 - A portion of the component is cut using a slow-cutting saw to expose a cross-sectional (thickness) of the component;

Step 2 - A sample of the cut component is prepared for metallographic examination. This preparation involves polishing the sample;

Step 3 – Images of the polished sample are captured via a scanning electron microscope. A back scattering technique is used to capture the images. The images are taken at a magnification, which gives a minimum of 150 contrasting features in the image to be analysed. These contrasting features can be pores or a combination of pores
 5 and second phase particles. More specifically, images are taken at magnifications, which enable the analysis of $10^2 - 10^3$ contrasting features;

Step 4 – The images are imported into Clémex Vision software, and a threshold is created between the contrasting features and the matrix of material. The software then counts the pixels of the contrasting features and transforms the count into dimensions
 10 according to a predetermined scale;

Step 5 – The imaging software then obtains values in terms of the spherical diameter, sphericity and pore size distribution of the contrasting features. The imaging software is able to use the above formula for calculating the sphericity of the pores. These analyses are done on several images taken in the same conditions on the microscope for a total
 15 number of analyzed features greater than 3000;

[064] When processing the contrasting features, it is assumed that the pores and the second phase particles are of roughly the same size.

20 [065] In accordance with the present invention, the static components of the gas turbine engine that are formed from the metal injection molding process have pores with an average sphericity greater than 0.5. A sphericity of 1 is close to perfect sphericity and a sphericity of 0 is substantially flat. In accordance with a more specific non-limiting embodiment, the pores have an average sphericity greater than 0.7. And in accordance
 25 with an even more specific non-limiting embodiment, the pores have an average sphericity of greater than 0.9.

[066] In the case of the micrograph shown in Figure 9, the software is instructed to provide values for the contrasting features that fall into the following three categories:
 30 a) contrasting features larger than $2\mu\text{m}^2$; b) contrasting features between 0.5 and $2\mu\text{m}^2$; and c) contrasting features smaller than $0.5\mu\text{m}^2$. The following table outlines the results for this micrograph:

Microstructural feature based on size (μm^2)	Mean Spherical Diameter (μm)	Sphericity
contrasting features larger than $2\mu\text{m}^2$	2.43	0.78
contrasting features between 0.5 and $2\mu\text{m}^2$	1.35	0.90
contrasting features smaller than $0.5\mu\text{m}^2$	0.50	0.99

Pore Size

[067] The pores contained within the static components produced from the metal injection molding procedure preferably have a pore size diameter of less than 10microns. In accordance with a more specific non-limiting example of implementation, the components have pores with an average pore size diameter of less than 5 microns. In accordance with a still more specific non-limiting example of implementation, at least 50% of the pores have a pore size diameter of less than 3 microns.

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[068] The above described process that uses a microscope for capturing images of the microstructure of the component and then a software program, such as Clémex Vision, to analyse the captured images can be used in order to obtain the values for the pore size of the pores within the components.

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Density

[069] The static components of the gas turbine engine formed from the metal injection molding procedure described above have a density that is less than the theoretical density possible for the material from which the components are made. This is due to the fact that as the binder is removed from the green part, voids are created between the powder particles. These voids turn into substantially spherical pores as the powder particles are thermally bonded together during the sintering process.

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[070] As a result, the component, whether it is a stator vane, a fuel swirler, a floating collar, a heat shield or a shroud segment, is less dense than the theoretical possible

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density for the material from which it is made. In other words, the component made from the metal injection process is less dense than if it had been machined from a solid block of the given material. In accordance with a non-limiting example, the static components formed from the above described metal injection process have a density of
5 between 96-99.5% of a theoretical possible density. In accordance with a further non-limiting example, the component has a density of between 97-98% of a theoretical possible density.

[071] The following is a non-limiting example of a method for measuring the density of
10 the components formed from the metal injection molding process described above. The density of the parts can be evaluated using Archimedes technique, wherein a part is weighed dry and is then weighed again when suspended in water. The difference in weights is due to a buoyant force created by the porosities. This difference in weights enables the calculation of density according to the following equation: SINTERED
15 $DENSITY = (dry\ mass * density\ of\ water) / (dry\ mass - wet\ mass)$.

[072] The following is a specific manner in which density is calculated:

Step 1 – A sample of the component is taken. The sample can be cut using a slow-cutting saw;

20 Step 2 – The dry sample is weighed using a measuring scale;

Step 3 – The sample is then suspended within a body of liquid, and the weight of the suspended sample is taken;

Step 4 – The density of the component is determined by entering the dry weight and the weight when suspended in water into the formula $DENSITY = (dry\ mass * density\ of\ water) / (dry\ mass - wet\ mass)$. The density can be calculated manually or using a
25 computer program.

[073] Density measurements by the Archimedes technique are ASTM B328 (which is a standard test method for density, oil content and interconnected porosity of sintered
30 metal structural parts) and ASTM B311 of MPIF std. 42.

[074] The above described metal injection process described above can be used to manufacture the stator vanes 28, the fuel swirler 30, the floating collar 32, the heat shield 34 and the shroud segment 50 of the gas turbine engine, such that these components have the density and pore characteristics described above. Some non-
5 limiting examples of each of these static components will now be described briefly below.

Stator vanes 28

[075] Shown in Figures 2a and 2b is a non-limiting example of a stator vane 28 suitable
10 for being produced in accordance with the metal injection process of the present invention. Stator vanes, such as the one shown in Figure 2a, are generally mounted to the inner walls 31 (shown in Figure 1) of the gas turbine engine 10, and are positioned before and after the fan blades 22 of the compressors 12 and the turbine blades 26 of the turbines 16. In operation, the stator vanes 28 are operative for directing airflow towards
15 the fan blades 22 and the turbine blades 26.

[076] The stator vane 28 shown in Figure 2a includes an airfoil portion 36, and has leading and trailing edges that are not straight. The interior of the stator vane 28 is hollow, thus making it a more complicated component to manufacture. The particular
20 configuration and shape of the stator vane 28 shown in Figure 2 was developed by Rolls Royce, and is described in more detail in U.S. patent 4,504,189. It should be appreciated that stator vanes 28 having any size, shape and configuration capable of being produced via the metal injection molding process that will be described in more detail below, are included within the spirit of the present invention.

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[077] In accordance with a non-limiting example of implementation, the stator vane 28 is made from an alloy in the group of alloys consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloys. The stator vane 28 has a wall portion that has a thickness in the range from about 0.065 to 0.25 of an inch. In
30 accordance with a more specific non-limiting example, the stator vane 28 has a wall portion that has a thickness in the range from 0.1-0.2 of an inch. In a still more specific

non-limiting embodiment, the stator vane 28 has a wall portion that has a thickness in the range of from 0.125-0.175 of an inch.

Fuel swirler

5 [078] Shown in Figure 3 is a non-limiting example of a fuel swirler 30 for a gas turbine engine that is suitable for being produced in accordance with the present invention. The fuel swirler 30 is operative for being mounted in proximity to an opening of the combustion chamber 14, so as to be able to provide an air/fuel mix to the combustion chamber 12.

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[079] The fuel swirler 30 shown in Figure 3 includes a ferrule 38 for supporting a fuel injector, swirl vanes 40 and a radial flange 42. The particular configuration and shape of the fuel swirler 30 shown in Figure 3 was developed by General Electric Company, and is described in more detail in U.S. patent 7,131,273. It should be appreciated that fuel
15 swirlers 30 having any size, shape and configuration capable of being produced via the metal injection molding process that will be described in more detail below, are included within the spirit of the present invention.

[080] In accordance with a non-limiting example of implementation, the fuel swirler 30
20 is made from an alloy in the group of alloys consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloys. The fuel swirler 30 has a wall portion that has a thickness in the range from about 0.065 to 0.25 of an inch. In accordance with a more specific non-limiting example, the fuel swirler 30 has a wall portion that has a thickness in the range from 0.1-0.2 of an inch. In a still more specific
25 non-limiting embodiment, the fuel swirler 30 has a wall portion that has a thickness in the range of from 0.125-0.175 of an inch.

Floating Collar

[081] Shown in Figure 4 is a non-limiting example of a floating collar 32 for a gas
30 turbine engine, suitable for being produced in accordance with the present invention. In operation, the floating collar 32 is positioned between the fuel swirler 30, or fuel injection nozzles, and the combustion chamber 14 for damping vibration, and

permitting minor relative movement between the fuel swirler or nozzles and the combustion chamber 14.

[082] The floating collar 32 shown in Figure 4 is in the shape of an annular ring. The particular configuration and shape of the floating collar 32 shown in Figure 4 was developed by Rolls Royce, and is described in more detail in U.S. patent 6,324,830. It should be appreciated that floating collars 32 having any size, shape and configuration capable of being produced via the metal injection molding process that will be described in more detail below, are included within the spirit of the present invention.

[083] In accordance with a non-limiting example of implementation, the floating collar 32 is made from an alloy in the group of alloys consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloys. The floating collar 32 has a wall portion that has a thickness in the range from about 0.065 to 0.25 of an inch. In accordance with a more specific non-limiting example, the stator vane has a wall portion that has a thickness in the range from 0.1-0.2 of an inch. In a still more specific non-limiting embodiment, the stator vane 28 has a wall portion that has a thickness in the range of from 0.125-0.175 of an inch.

Heat shield

[084] Shown in Figure 5 is a non-limiting example of a heat shield 34 suitable for being produced in accordance with the present invention. In operation, the heat shield 34 is positioned at a head area of the combustion chamber 14 for protecting the head area of the combustion chamber 14 from the effects of the hot gasses and radiation caused by ignition reactions that take place in the combustion chamber 14.

[085] The heat shield 34 shown in Figure 5 includes a through hole 44 for the burner and a plurality of air passage holes 46. The particular configuration and shape of the heat shield 34 shown in Figure 5 was developed by BMW Rolls Royce, and is described in more detail in U.S. patent 5,956,955. It should be appreciated that heat shields 34 having any size, shape and configuration capable of being produced via the metal

injection molding process that will be described in more detail below, are included within the spirit of the present invention.

[086] In accordance with a non-limiting example of implementation, the heat shield 34 is made from an alloy in the group of alloys consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloys. The heat shield 34 has a wall portion that has a thickness in the range from about 0.065 to 0.25 of an inch. In accordance with a more specific non-limiting example, the heat shield 34 has a wall portion that has a thickness in the range from 0.1-0.2 of an inch. In a still more specific non-limiting embodiment, the heat shield 34 has a wall portion that has a thickness in the range of from 0.125-0.175 of an inch.

Shroud Segment

[087] Shown in Figure 6 is a non-limiting example of a shroud segment 50 suitable for being produced in accordance with the present invention. A shroud assembly that is made up of a plurality of shroud segments 50 encircles the turbine blades 26.

[088] The shroud segment 50 shown in Figure 6 includes a shroud body 52 formed with a forward side mounting rail 54 and an aft side mounting rail 56 and a concavely arcuate inner face 58. The particular configuration and shape of the shroud segment 50 shown in Figure 6 was developed by General Electric Company, and is described in more detail in U.S. patent 5,071,313. It should be appreciated that shroud segments 50 having any size, shape and configuration capable of being produced via the metal injection molding process that will be described in more detail below, are included within the spirit of the present invention.

[089] In accordance with a non-limiting example of implementation, the shroud segment 50 is made from an alloy in the group of alloys consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloys. The shroud segment 50 has a wall portion that has a thickness in the range from about 0.065 to 0.25 of an inch. In accordance with a more specific non-limiting example, the shroud segment 50 has a wall portion that has a thickness in the range from 0.1-0.2 of an inch.

In a still more specific non-limiting embodiment, the shroud segment 50 has a wall portion that has a thickness in the range of from 0.125-0.175 of an inch.

Recipe for making Static Components

5 [090] The following describes suitable feedstock and operating parameters for manufacturing a stator vane 28, a fuel swirler 30, a floating collar 32, a heat shield 34 and a shroud segment 50 in accordance with the metal injection molding process described above. In accordance with a specific embodiment, the feedstock includes a powder of gas atomised Inconel 625 with 80% of the particles having a diameter of less
10 than 22 microns, and a binder that is made of 85% paraffin wax, 5% bees wax, 5% stearic acid and 5% PE-EVA copolymer. The powder and binder are mixed together in proportions suitable for forming a feedstock having between 60-70% solid loading. The powder and binder feedstock is kept at a temperature of 90C.

15 [091] Once mixed, the feedstock is injected into a mold that is made out of steel (P20). The mold is kept at a temperature between 25-40C and preferably between 30-35C. The feedstock is injected into the mold such that the feedstock is pushed into the mold at a pressure below 60psi and preferably at a pressure of between 20-40 psi. More specifically, the feedstock is injected into the mold with low pressure such that there is
20 no shearing separation between the powder and the binder as it is being injected. The cycle time used to mold the part is less than 30 seconds.

[092] Once the shaped part is removed from the mold, the debinding process is conducted in a wicking media of high purity alumina powders. More specifically, the
25 parts are buried in the wicking media. The debinding treatment is then conducted under argon gas. The temperature profile applied to the part is as follows: 1) the heat is ramped to 200C at a rate of 0.5C/min, and then 2) the heat is ramped from 200C to 900C at 0.85C/min. Once the heat has reached 900C, it is then held at 900C for 2 hours, after which time the heat is ramped back down to an ambient temperature.

[093] Once the debinding process is complete, the parts are sintered under a hydrogen/argon atmosphere mixture at 1245C for 2 hours. The parts are placed on low-density alumina setters during this process.

5 Conclusion

[094] Due to the porous nature of the components formed by the metal injection molding process described above, it is not necessarily advisable to form the moving components of the gas turbine engine using this process. The performance and quality standards that are applied to the dynamic, rotating components of the gas turbine engine are more stringent than those for the static components since it is possible that pores within moving components may cause cracks to propagate much more readily than in static components.

[095] Referring back to Figure 1, in accordance with a non-limiting example of implementation, the gas turbine engine 10 includes a hot section, in which is mounted the rotating assembly and the plurality of static components. In accordance with the present invention, at least one of the static components is made by metal injection molding from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloys. Alternatively, any alloy that has desired material characteristics for the end part can also be used. As such, the static component that is formed from the metal injection molding process has a density of less than 100% of its theoretical possible density, while the components that form the rotating assembly have a density of 100% of their theoretical possible density. This difference in density is caused, at least in part by the fact that the static components formed from the metal injection molding process are more porous than the components that form the rotating assembly. In general, the components that form the rotating assembly are manufactured by techniques, such as machining, that cause these components to be substantially free of pores.

[096] Although the present invention has been described in considerable detail with reference to certain preferred embodiments thereof, variations and refinements are

possible without departing from the spirit of the invention. Therefore, the scope of the invention should be limited only by the appended claims and their equivalents.

CLAIMS:

- 1) A static component for a gas turbine engine, said static component being made from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and having a density less than 99% of a theoretical possible density for the alloy, said static component being made by a metal injection molding process.
- 2) A static component as defined in claim 1, wherein said static component is selected from the group consisting of a collar for mounting to a combustor and for receiving a fuel injection nozzle, a heat shield for mounting to a combustor, a stator vane, a fuel swirler and a shroud segment.
- 3) A static component as defined in claim 2, having a density in excess of about 96% of the theoretical possible density for the alloy.
- 4) A static component as defined in claim 3, having a density between 97-98% of a theoretical possible density.
- 5) A static component as defined in claim 1, having a wall portion that has a thickness in the range from about 0.065- 0.25 inches.
- 6) A static component as defined in claim 5, having a wall portion that has a thickness in the range from about 0.1-0.2 inches.
- 7) A static component as defined in claim 6, having a wall portion that has a thickness in the range of from about 0.125-0.175 inches.
- 8) A precursor for a static component for a gas turbine engine, said precursor being made from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and having a density less than 99% of a theoretical possible density for the alloy, said precursor being made by a metal injection molding process.

- 9) A precursor as defined in claim 8, wherein said static component is selected from the group consisting of a collar for mounting to a combustor and for receiving a fuel injection nozzle, a heat shield for mounting to a combustor, a stator vane, a fuel swirler and a shroud segment.
- 10) A precursor as defined in claim 9, having a density in excess of about 96% of a theoretical possible density for the alloy.
- 11) A precursor as defined in claim 10, having a density between 97-98% of a theoretical possible density.
- 12) A precursor as defined in claim 9, having a wall portion that has a thickness in the range from about 0.065- 0.25 inches.
- 13) A precursor as defined in claim 12, having a wall portion that has a thickness in the range from about 0.1-0.2 inches
- 14) A precursor as defined in claim 13, having a wall portion that has a thickness in the range from about 0.125-0.175 inches.
- 15) A process for making a static component for a gas turbine engine, said process comprising:
 - a) preparing a fluid feedstock including metallic powder selected from the group consisting Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and binder material;
 - b) injecting the feedstock into a mold having cavity approximating the shape of the static component, to form a green part;
 - c) debinding the green part to provide a debound part;
 - d) sintering the debound part to yield said static component, wherein said preparing, injecting, debinding and sintering being performed at process conditions such that said static component has a density less than 99% of a theoretical possible density for the alloy.

- 16) A process as defined in claim 15, wherein said static component is selected from the group consisting of a collar for mounting to a combustor and for receiving a fuel injection nozzle, a heat shield for mounting to a combustor, a stator vane, a fuel swirler and a shroud segment.
- 17) A process as defined in claim 16, wherein said static component has a density in excess of 96% of a theoretical possible density for the alloy.
- 18) A process as defined in claim 17, wherein said static component has a density in the range of between 97-98% of a theoretical possible density.
- 19) A process as defined in claim 16, wherein said static component has a wall portion that has a thickness in the range from about 0.065- 0.25 inches.
- 20) A process as defined in claim 19, wherein said static component has a wall portion that has a thickness in the range from about 0.1-0.2 inches.
- 21) A process as defined in claim 20, wherein said static component has a wall portion that has a thickness in the range from about 0.125-0.175 inches.
- 22) A process for making a static component for a gas turbine engine, said process comprising:
 - a) preparing a fluid feedstock including metallic powder selected from the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and binder material;
 - b) injecting the feedstock into a mold having cavity approximating the shape of the static component, to form a green part;
 - c) debinding the green part to provide a debound part;
 - d) sintering the debound part to yield a precursor of said static component, wherein said preparing, injecting, debinding and sintering being performed at process conditions such that said precursor has a density less than 99% of a theoretical possible density for the alloy;

- e) performing one or more process step on said precursor to yield said static component, wherein said one or more process steps are such that said static component acquires a higher density than said precursor.
- 23) A process as defined in claim 22, wherein said static component is selected from the group consisting of a collar for mounting to a combustor and for receiving a fuel injection nozzle, a heat shield for mounting to a combustor, a stator vane, a fuel swirler and a shroud segment.
- 24) A process as defined in claim 23, wherein said process step includes a process selected from the group consisting of an isostatic pressing operation, finishing machining, surface treatments and heat treating.
- 25) A process as defined in claim 23, wherein said precursor has a density in excess of 96% of a theoretical possible density for the alloy.
- 26) A process as defined in claim 25, wherein said precursor has a density between 97-98% of a theoretical possible density.
- 27) A process as defined in claim 23, wherein said precursor has a wall portion that has a thickness in the range from about 0.065- 0.25 inches.
- 28) A process as defined in claim 27, wherein said precursor has a wall portion that has a thickness in the range from about 0.1-0.2 inches.
- 29) A process as defined in claim 28, wherein said precursor having a wall portion that has a thickness in the range of from about 0.125-0.175 inches.
- 30) A static component of a gas turbine engine, said static component being made from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and having pores throughout, said pores having an average sphericity greater than 0.5, said static component being made by a metal injection molding process.

- 31) A static component as defined in claim 30, wherein said static component is selected from the group consisting of a collar for mounting to a combustor and for receiving a fuel injection nozzle, a heat shield for mounting to a combustor, a stator vane, a fuel swirler and a shroud segment.
- 32) A static component as defined in claim 31, wherein said pores donate to said static component a density of less than 99%.
- 33) A static component as defined in claim 32, said pores having an average sphericity greater than 0.7.
- 34) A static component as defined in claim 33, said pores having an average sphericity greater than 0.9.
- 35) A static component as defined in claim 32, having a density in excess of about 96% of a theoretical possible density for the alloy.
- 36) A static component as defined in claim 35, having a density between 97-98%.
- 37) A static component as defined in claim 32, having a wall portion that has a thickness in the range from about 0.065- 0.25 inches.
- 38) A static component as defined in claim 37, having a wall portion that has a thickness in the range from about 0.1-0.2 inches.
- 39) A static component as defined in claim 38, having a wall portion that has a thickness in the range of from about 0.125-0.175 inches.
- 40) A precursor for a static component for a gas turbine engine, for receiving a fuel injector, said precursor being made from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and having pores throughout, said pores having an average sphericity greater than 0.5, said static component being made by a metal injection molding process.

- 41) A precursor as defined in claim 40, wherein said static component is selected from the group consisting of a collar for mounting to a combustor and for receiving a fuel injection nozzle, a heat shield for mounting to a combustor, a stator vane, a fuel swirler and a shroud segment.
- 42) A precursor as defined in claim 41, wherein said pores donate to said precursor a density of less than 99% of a theoretical possible density for the alloy.
- 43) A precursor as defined in claim 42, said pores having an average sphericity greater than 0.7.
- 44) A precursor as defined in claim 43, said pores having an average sphericity greater than 0.9.
- 45) A precursor as defined in claim 42, having a density in excess of about 96% of a theoretical possible density for the alloy.
- 46) A precursor as defined in claim 45, having a density between 97-98%.
- 47) A precursor as defined in claim 42, having a wall portion that has a thickness in the range from about 0.065- 0.25 inches.
- 48) A precursor as defined in claim 47, having a wall portion that has a thickness in the range from about 0.1-0.2 inches.
- 49) A precursor as defined in claim 48, having a wall portion that has a thickness in the range of from about 0.125-0.175 inches.
- 50) A process for making a static component for a gas turbine engine, said process comprising:
- a) preparing a fluid feedstock including metallic powder selected from the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and binder material;

- b) injecting the feedstock into a mold having cavity approximating the shape of the static component, to form a green part;
- c) debinding the green part to provide a debound part;
- d) sintering the debound part to yield said static component, wherein said preparing, injecting, debinding and sintering being performed at process conditions such that said static component has pores throughout, said pores having an average sphericity greater than 0.5.

51) A process as defined in claim 50, wherein said static component is selected from the group consisting of a collar for mounting to a combustor and for receiving a fuel injection nozzle, a heat shield for mounting to a combustor, a stator vane, a fuel swirler and a shroud segment.

52) A process as defined in claim 51, wherein said pores donate to said static component a density of less than 99% of a theoretical possible density for the alloy.

53) A process as defined in claim 52, wherein said pores have an average sphericity greater than 0.7.

54) A process as defined in claim 53, wherein said pores have an average sphericity greater than 0.9.

55) A process as defined in claim 52, having a density in excess of about 96% of a theoretical possible density for the alloy.

56) A process as defined in claim 55, having a density between 97-98%.

57) A process as defined in claim 52, wherein said static component has a wall portion that has a thickness in the range from about 0.065- 0.25 inches.

58) A process as defined in claim 57, wherein said static component has a wall portion that has a thickness in the range from about 0.1-0.2 inches.

- 59) A process as defined in claim 58, wherein said static component has a wall portion that has a thickness in the range of from about 0.125-0.175 inches.
- 60) A static component for a gas turbine engine, said static component being made from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and having pores throughout, said pores having an average pore size diameter of less than 10 microns, said static component being made by a metal injection molding process.
- 61) A static component as defined in claim 60, wherein said static component is selected from the group consisting of a collar for mounting to a combustor and for receiving a fuel injection nozzle, a heat shield for mounting to a combustor, a stator vane, a fuel swirler and a shroud segment.
- 62) A static component as defined in claim 61, wherein said pores donate to said static component a density of less than 99% of a theoretical possible density for the alloy.
- 63) A static component as defined in claim 62, said pores having an average pore size diameter of less than 5 microns.
- 64) A static component as defined in claim 63, at least 50% of said pores having an average pore size diameter of less than 3 microns.
- 65) A static component as defined in claim 64, having a density in excess of about 96% of a theoretical possible density for the alloy.
- 66) A static component as defined in claim 65, having a density between 97-98% of a theoretical possible density for the alloy.
- 67) A static component as defined in claim 62, having a wall portion that has a thickness in the range from about 0.065- 0.25 inches.

- 68) A static component as defined in claim 67, having a wall portion that has a thickness in the range from about 0.1-0.2 inches.
- 69) A static component as defined in claim 68, having a wall portion that has a thickness in the range of from about 0.125-0.175 inches.
- 70) A precursor for a static component for a gas turbine engine, said precursor being made from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and having pores throughout, said pores having an average pore size diameter of less than 10 microns, said static component being made by a metal injection molding process.
- 71) A precursor as defined in claim 70, wherein said static component is selected from the group consisting of a collar for mounting to a combustor and for receiving a fuel injection nozzle, a heat shield for mounting to a combustor, a stator vane, a fuel swirler and a shroud segment.
- 72) A precursor as defined in claim 71, wherein said pores donate to said precursor a density of less than 99% of a theoretical possible density for the alloy.
- 73) A precursor as defined in claim 72, said pores having an average pore size diameter of less than 5 microns
- 74) A precursor as defined in claim 73, at least 50% of said pores having an average pore size diameter of less than 3 microns.
- 75) A precursor as defined in claim 72, having a density in excess of about 96% of a theoretical possible density for the alloy.
- 76) A precursor as defined in claim 75, having a density between 97-98% of a theoretical possible density for the alloy.
- 77) A precursor as defined in claim 72, having a wall portion that has a thickness in the range from about 0.065- 0.25 inches.

- 78) A precursor as defined in claim 77, having a wall portion that has a thickness in the range from about 0.1-0.2 inches.
- 79) A precursor as defined in claim 78, having a wall portion that has a thickness in the range of from about 0.125-0.175 inches.
- 80) A process for making a static component for a gas turbine engine, said process comprising:
- a) preparing a fluid feedstock including metallic powder selected from the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and binder material;
 - b) injecting the feedstock into a mold having cavity approximating the shape of the static component, to form a green part;
 - c) debinding the green part to provide a debound part;
 - d) sintering the debound part to yield said static component, wherein said preparing, injecting, debinding and sintering being performed at process conditions such that said static component has pores throughout, said pores having an average pore size diameter of less than 10 microns.
- 81) A process as defined in claim 80, wherein said static component is selected from the group consisting of a collar for mounting to a combustor and for receiving a fuel injection nozzle, a heat shield for mounting to a combustor, a stator vane, a fuel swirler and a shroud segment.
- 82) A process as defined in claim 81, wherein said pores donate to said static component a density of less than 99% of a theoretical possible density for the alloy.
- 83) A process as defined in claim 82, said pores having an average pore size diameter of less than 5 microns.
- 84) A process as defined in claim 83, at least 50% of said pores having an average pore size diameter of less than 3 microns.

- 85) A process as defined in claim 82, having a density in excess of about 96% of a theoretical possible density for the alloy.
- 86) A process as defined in claim 85, having a density between 97-98% of a theoretical possible density for the alloy.
- 87) A process as defined in claim 82, wherein said static component has a wall portion that has a thickness in the range from about 0.065- 0.25 inches.
- 88) A process as defined in claim 87, wherein said static component has a wall portion that has a thickness in the range from about 0.1-0.2 inches.
- 89) A process as defined in claim 88, wherein said static component has a wall portion that has a thickness in the range of from about 0.125-0.175 inches.
- 90) A process for making a static component for a gas turbine engine, said process comprising:
- a) preparing a fluid feedstock including metallic powder selected from the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and binder material;
 - b) injecting the feedstock into a mold having cavity approximating the shape of the static component, to form a green part;
 - c) debinding the green part to provide a debound part;
 - d) sintering the debound part to yield a precursor of said static component, wherein said preparing, injecting, debinding and sintering being performed at process conditions such that said precursor has pores throughout, said pores having an average pore size diameter of less than 10 microns;
 - e) performing one or more process steps on said precursor to yield said static component, wherein said one or more process steps are such that said static component acquires a higher density than said precursor.
- 91) A process as defined in claim 90, wherein said static component is selected from the group consisting of a collar for mounting to a combustor and for receiving a

fuel injection nozzle, a heat shield for mounting to a combustor, a stator vane, a fuel swirler and a shroud segment.

- 92) A process as defined in claim 91, wherein said one or more process steps includes a process selected from the group consisting of an isostatic pressing operation, finishing machining, surface treatments and heat treating.
- 93) A process as defined in claim 92, wherein said precursor has a density of less than 99% of a theoretical possible density for the alloy.
- 94) A process as defined in claim 93, wherein said precursor has pores having an average pore size diameter of less than 5 microns.
- 95) A process as defined in claim 94, wherein said precursor has at least 50% of said pores having an average pore size diameter of less than 3 microns.
- 96) A process as defined in claim 93, wherein said precursor has a density in excess of 96% of a theoretical possible density for the alloy.
- 97) A process as defined in claim 96, wherein said precursor has a density between 97-98% of a theoretical possible density for the alloy.
- 98) A process as defined in claim 93, wherein said precursor has a wall portion that has a thickness in the range from about 0.065- 0.25 inches.
- 99) A process as defined in claim 96, wherein said precursor has a wall portion that has a thickness in the range from about 0.1-0.2 inches.
- 100) A process as defined in claim 97, wherein said precursor having a wall portion that has a thickness in the range of from about 0.125-0.175 inches.
- 101) A set of static component for a gas turbine engine, each static component being made from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy, wherein:

- a) said set of static components is made by metal injection molding process from a common mold having a component-shaped cavity;
 - b) each static component of said set of static components is produced during a different molding cycle of the common mold;
 - c) said set of static components have dimensional tolerances variation of less than 0.5% between static components in said set.
- 102) A set of static components as defined in claim 101, wherein said static component is selected from the group consisting of a collar for mounting to a combustor and for receiving a fuel injection nozzle, a heat shield for mounting to a combustor, a stator vane, a fuel swirler and a shroud segment.
- 103) A set of static components as defined in claim 102, wherein said set of static components includes between 200-800 parts.
- 104) A set of static components as defined in claim 103, wherein each static component of said set has a density of less than 99% of a theoretical possible density for the alloy.
- 105) A set of static components as defined in claim 104, wherein each static component of said set has a density in excess of about 96% of a theoretical possible density for the alloy.
- 106) A set of static components as defined in claim 105, wherein each static component of said set has a density between 97-98% of a theoretical possible density.
- 107) A set of static components as defined in claim 102, wherein each static component of said set has a wall portion that has a thickness in the range from about 0.065- 0.25 inches.
- 108) A set of static components as defined in claim 107, wherein each static component of said set has a wall portion that has a thickness in the range from about 0.1-0.2 inches

- 109) A set of static components as defined in claim 108, wherein each static component of said set has a wall portion that has a thickness in the range from about 0.125-0.175 inches.
- 110) A process for making a set of static components for a gas turbine engine, said process comprising:
- a) preparing a fluid feedstock including metallic powder selected from the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and binder material;
 - b) injecting the feedstock into a mold having cavity approximating the shape of the static component, to form a green part;
 - c) debinding the green part to provide a debound part;
 - d) sintering the debound part to yield said static component, wherein said preparing, injecting, debinding and sintering being performed at process conditions such that said static component has pores throughout, said pores having an average pore size diameter of less than 10 microns.
- 111) A process as defined in claim 110, wherein said static component is selected from the group consisting of a collar for mounting to a combustor and for receiving a fuel injection nozzle, a heat shield for mounting to a combustor, a stator vane, a fuel swirler and a shroud segment.
- 112) A process as defined in claim 111, wherein said pores donate to said static component a density of less than 99% of a theoretical possible density for the alloy.
- 113) A process as defined in claim 111, wherein said pores having an average pore size diameter of less than 5 microns.
- 114) A process as defined in claim 113, wherein at least 50% of said pores having an average pore size diameter of less than 3 microns..

- 115) A process as defined in claim 111, having a density in excess of about 96% of a theoretical possible density for the alloy.
- 116) A process as defined in claim 115, having a density between 97-98% of a theoretical possible density for the alloy.
- 117) A process as defined in claim 111, wherein said static component has a wall portion that has a thickness in the range from about 0.065- 0.25 inches.
- 118) A process as defined in claim 117, wherein said static component has a wall portion that has a thickness in the range from about 0.1-0.2 inches.
- 119) A process as defined in claim 118, wherein said static component has a wall portion that has a thickness in the range of from about 0.125-0.175 inches.
- 120) A process for making a set of static components for a gas turbine engine, said process comprising:
- a) preparing a fluid feedstock including metallic powder selected from the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and binder material;
 - b) injecting the feedstock into a mold having static component-shaped cavity to form a green part;
 - c) debinding the green part to provide a debound part;
 - d) sintering the debound part to yield a static component of said set;
 - e) repeating said, injecting, debinding and sintering a number of times sufficient to make all the static components of said set of static components, wherein said preparing, injecting, debinding and sintering being performed at process conditions such that said set of static components has dimensional tolerances variation of less than 0.5% between static components in said set.
- 121) A process as defined in claim 120, wherein said static component is selected from the group consisting of a collar for mounting to a combustor and for receiving a fuel injection nozzle, a heat shield for mounting to a combustor, a stator vane, a fuel swirler and a shroud segment.

- 122) A process as defined in claim 121, wherein said set of static components includes between 200-800 parts.
- 123) A process as defined in claim 122, wherein each static component of said set has a density of less than 99% of a theoretical possible density for the alloy.
- 124) A process as defined in claim 123, wherein each of said static components has a density in excess of 96% of a theoretical possible density for the alloy.
- 125) A process as defined in claim 124, wherein each of said static components has a density between 97-98% of a theoretical possible density for the alloy.
- 126) A process as defined in claim 122, wherein each of said static components of said set has a wall portion that has a thickness in the range from about 0.065- 0.25 inches.
- 127) A process as defined in claim 126, wherein each of said static components of said set has a wall portion that has a thickness in the range from about 0.1-0.2 inches.
- 128) A process as defined in claim 127, wherein each of said static components of said set has a wall portion that has a thickness in the range of from about 0.125-0.175 inches.
- 129) A gas turbine engine including a hot section in which is mounted a rotating assembly and a plurality of static components about which said rotating assembly turns during operation of said gas turbine engine, at least one of said static components being made by metal injection molding from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy and having pores throughout which donate to said at least one static component a density less than 100% of a theoretical possible density for the alloy.

- 130) A gas turbine engine as defined in claim 129, wherein said at least one of said static components has more porosity than said rotating assembly.
- 131) A gas turbine engine as defined in claim 130, wherein said rotating assembly is substantially free of pores.
- 132) A gas turbine engine as defined in claim 130, wherein said at least one of said static components is selected from the group consisting of a collar for mounting to a combustor and for receiving a fuel injection nozzle, a heat shield for mounting to a combustor, a stator vane, a fuel swirler and a shroud segment.
- 133) A gas turbine engine as defined in claim 132, wherein said rotating assembly includes a shaft.
- 134) A gas turbine engine as defined in claim 133, wherein said rotating assembly includes a plurality of blades mounted to said shaft.
- 135) A gas turbine engine as defined in claim 134, wherein said at least one of said static components has a density in excess of about 96% of a theoretical possible density for the alloy.
- 136) A gas turbine engine as defined in claim 135, wherein said at least one of said static components has a density between 97-98% of a theoretical possible density.
- 137) A gas turbine engine as defined in claim 134, wherein said at least one of said static components has a wall portion that has a thickness in the range from about 0.065- 0.25 inches.
- 138) A gas turbine engine as defined in claim 137, wherein said at least one of said static components has a wall portion that has a thickness in the range from about 0.1-0.2 inches.

- 139) A gas turbine engine as defined in claim 138, wherein said at least one of said static components has a wall portion that has a thickness in the range of from about 0.125-0.175 inches.
- 140) A gas turbine engine as defined in claim 134, wherein the pores of said at least one of said static components have an average sphericity greater than 0.5.
- 141) A gas turbine engine as defined in claim 140, wherein the pores of said at least one of said static components have an average sphericity greater than 0.7.
- 142) A gas turbine engine as defined in claim 141, wherein the pores of said at least one of said static components have an average sphericity greater than 0.9.
- 143) A gas turbine engine as defined in claim 134, wherein the pores of said at least one of said static components have an average pore size diameter of less than 10 microns.
- 144) A gas turbine engine as defined in claim 143, wherein the pores of said at least one of said static components have an average pore size diameter of less than 5 microns.
- 145) A gas turbine engine as defined in claim 144, wherein the pores of said at least one of said static components have an average pore size diameter of less than 3 microns.
- 146) A process for making a gas turbine engine including a hot section in which is mounted a rotating assembly and a plurality of static components about which said rotating assembly turns during operation of said gas turbine engine, said process comprising:
- a) making at least one of said static components by metal injection molding from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy, wherein said metal injection molding is characterized by process conditions that donate to said at least one static component pores throughout which reduce the density of said at least

- one of said static components below 100% of a theoretical possible density for the alloy;
- b) providing the remaining components of said gas turbine engine and assembling said gas turbine engine.
- 147) A process as defined in claim 146, wherein said at least one of said static components has more porosity than said rotating assembly.
- 148) A process as defined in claim 147, wherein said rotating assembly is substantially free of pores.
- 149) A process as defined in claim 148, wherein said at least one of said static components is selected from the group consisting of a collar for mounting to a combustor and for receiving a fuel injection nozzle, a heat shield for mounting to a combustor, a stator vane, a fuel swirler and a shroud segment.
- 150) A process as defined in claim 146, wherein said rotating assembly includes a shaft.
- 151) A process as defined in claim 150, wherein said rotating assembly includes a plurality of blades mounted to said shaft.
- 152) A process as defined in claim 146, wherein said at least one of said static components has a density in the range of about 99% to about 96% of a theoretical possible density for the alloy.
- 153) A process as defined in claim 152, wherein said at least one of said static components has a density between 97-98% of a theoretical possible density for the alloy.
- 154) A process as defined in claim 146, wherein said at least one of said static components has a wall portion that has a thickness in the range from about 0.065-0.25 inches.

- 155) A process as defined in claim 154, wherein said at least one of said static components has a wall portion that has a thickness in the range from about 0.1-0.2 inches.
- 156) A process as defined in claim 155, wherein said at least one of said static components has a wall portion that has a thickness in the range of from about 0.125-0.175 inches.
- 157) A process as defined in claim 146, wherein the pores of said at least one of said static components have an average sphericity greater than 0.5.
- 158) A process as defined in claim 157, wherein the pores of said at least one of said static components have an average sphericity greater than 0.7.
- 159) A process as defined in claim 158, wherein the pores of said at least one of said static components have an average sphericity greater than 0.9.
- 160) A process as defined in claim 146, wherein the pores of said at least one of said static components have an average pore size diameter of less than 10 microns.
- 161) A process as defined in claim 160, wherein the pores of said at least one of said static components have an average pore size diameter of less than 7 microns.
- 162) A process as defined in claim 161, wherein the pores of said at least one of said static components have an average pore size diameter of less than 5 microns.
- 163) A process for making a gas turbine engine including a hot section in which is mounted a rotating assembly and a plurality of static components about which said rotating assembly turns during operation of said gas turbine engine, said process comprising:
- a) making a precursor of at least one of said static components by metal injection molding from an alloy in the group consisting of Inconel 625, Inconel 718, MAR-M 247 or any nickel, cobalt or nickel-iron superalloy, wherein said metal injection molding is characterized by process conditions that donate to

- said precursor pores throughout which reduce the density of said precursor below 100% of a theoretical possible density for the alloy;
- b) performing one or more process step on said precursor to yield said at least one of said static components, wherein said one or more process steps are such that said at least one of said static components acquires a higher density than said precursor.
 - c) providing the remaining components of said gas turbine engine and assembling said gas turbine engine.
- 164) A process as defined in claim 163, wherein said precursor has a density in excess of 96% of a theoretical possible density for the alloy.
- 165) A process as defined in claim 164, wherein said precursor has a density between 97-98% of a theoretical possible density for the alloy.
- 166) A process as defined in claim 163, wherein said precursor has a wall portion that has a thickness in the range from about 0.065- 0.25 inches.
- 167) A process as defined in claim 166, wherein said precursor has a wall portion that has a thickness in the range from about 0.1-0.2 inches.
- 168) A process as defined in claim 167, wherein said precursor having a wall portion that has a thickness in the range of from about 0.125-0.175 inches.
- 169) A process as defined in claim 163, wherein said precursor has more porosity than said rotating assembly.
- 170) A process as defined in claim 169, wherein said rotating assembly is substantially free of pores.
- 171) A process as defined in claim 163, wherein said at least one of said static components is selected from the group consisting of a collar for mounting to a combustor and for receiving a fuel injection nozzle, heat shield for mounting to a combustor, a stator vane, a fuel swirler and a shroud segment.

- 172) A process as defined in claim 163, wherein said rotating assembly includes a shaft.
- 173) A process as defined in claim 172, wherein said rotating assembly includes a plurality of blades mounted to said shaft.
- 174) A process as defined in claim 163, wherein the pores of said precursor have an average sphericity greater than 0.5.
- 175) A process as defined in claim 174, wherein the pores of said precursor have an average sphericity greater than 0.7.
- 176) A process as defined in claim 175, wherein the pores of said precursor have an average sphericity greater than 0.9.
- 177) A process as defined in claim 163, wherein the pores of said precursor have an average pore size diameter of less than 10 microns.
- 178) A process as defined in claim 177, wherein the pores of said precursor have an average pore size diameter of less than 5 microns.
- 179) A process as defined in claim 178, wherein at least 50% of said pores having an average pore size diameter of less than 3 microns.

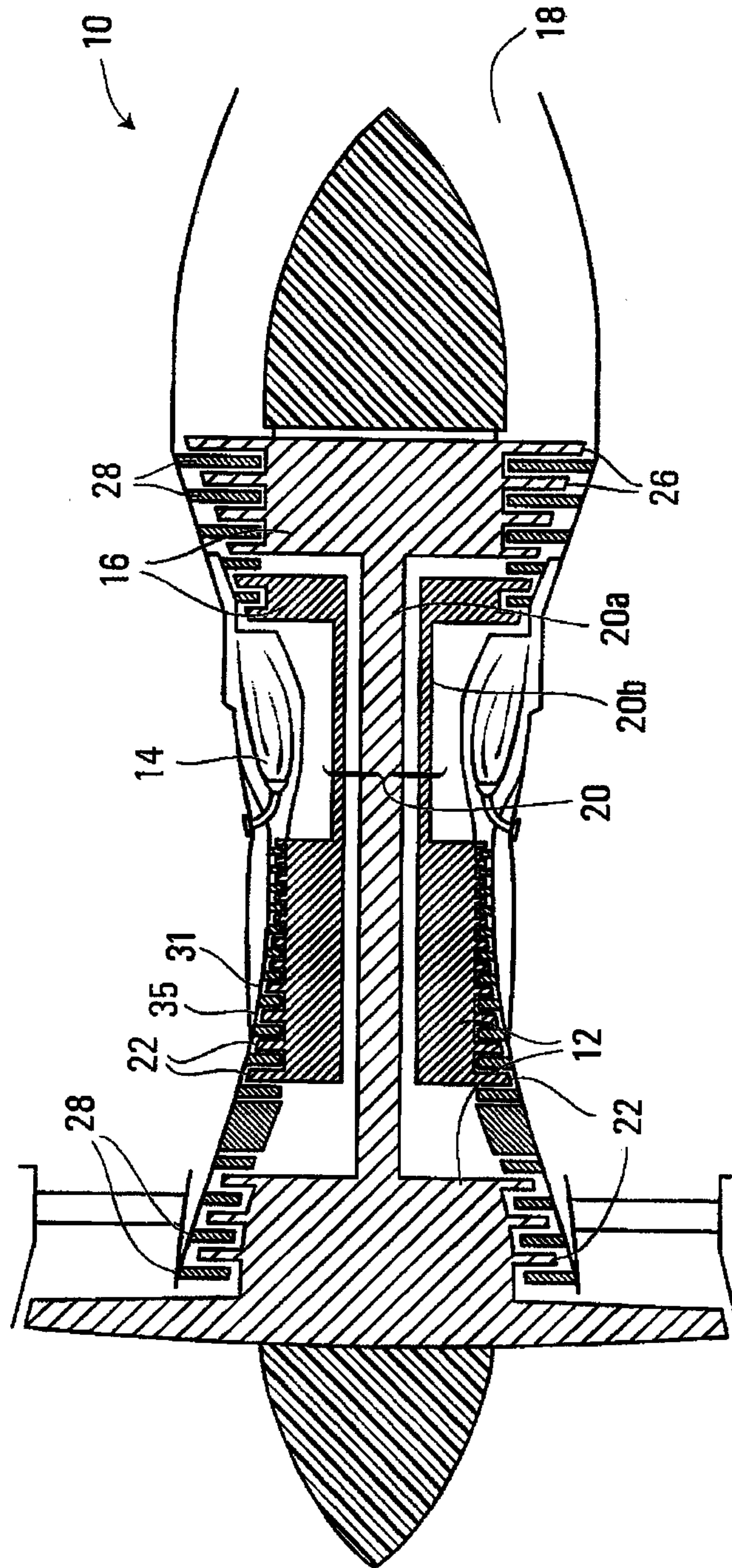


FIG. 1

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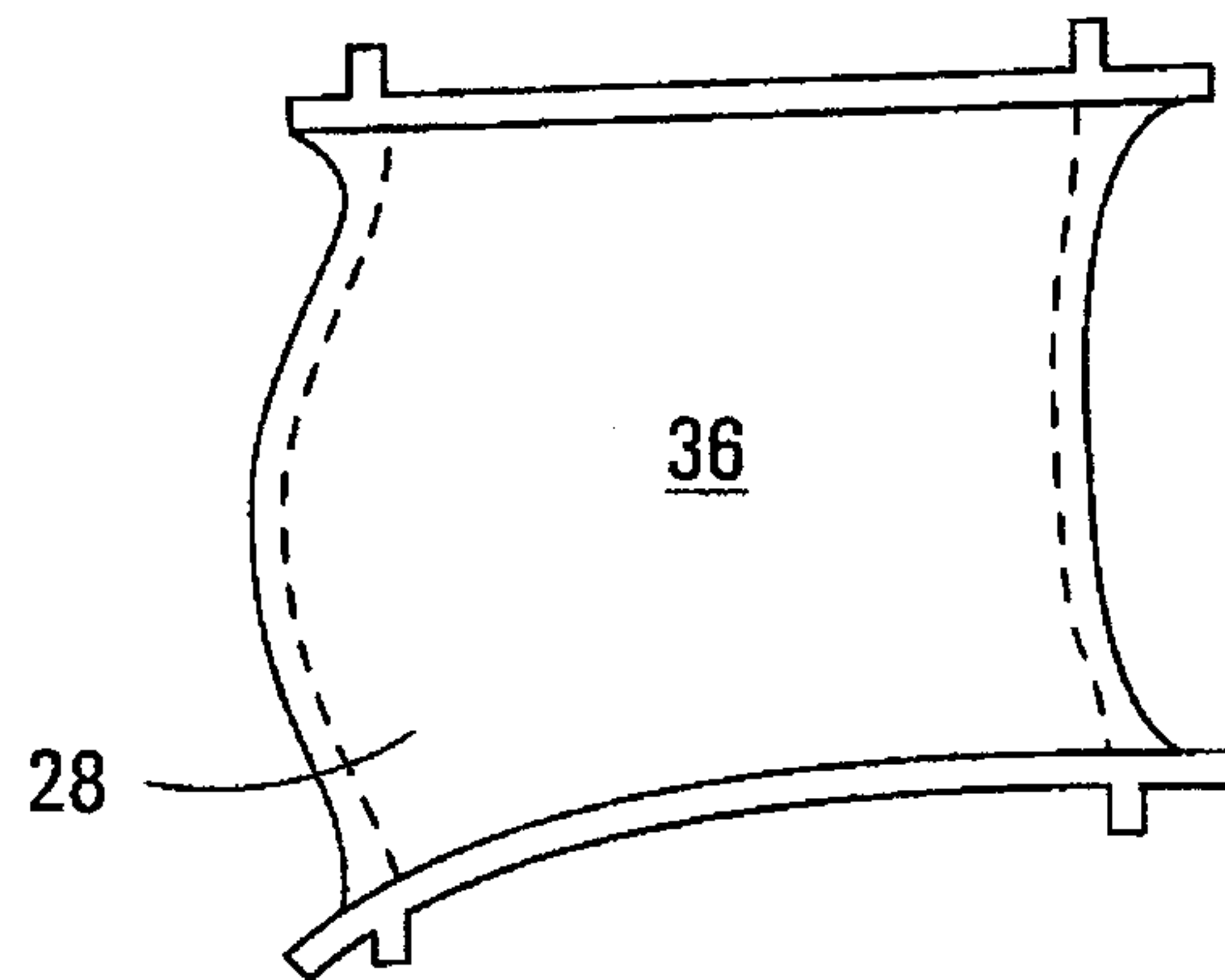


FIG. 2A

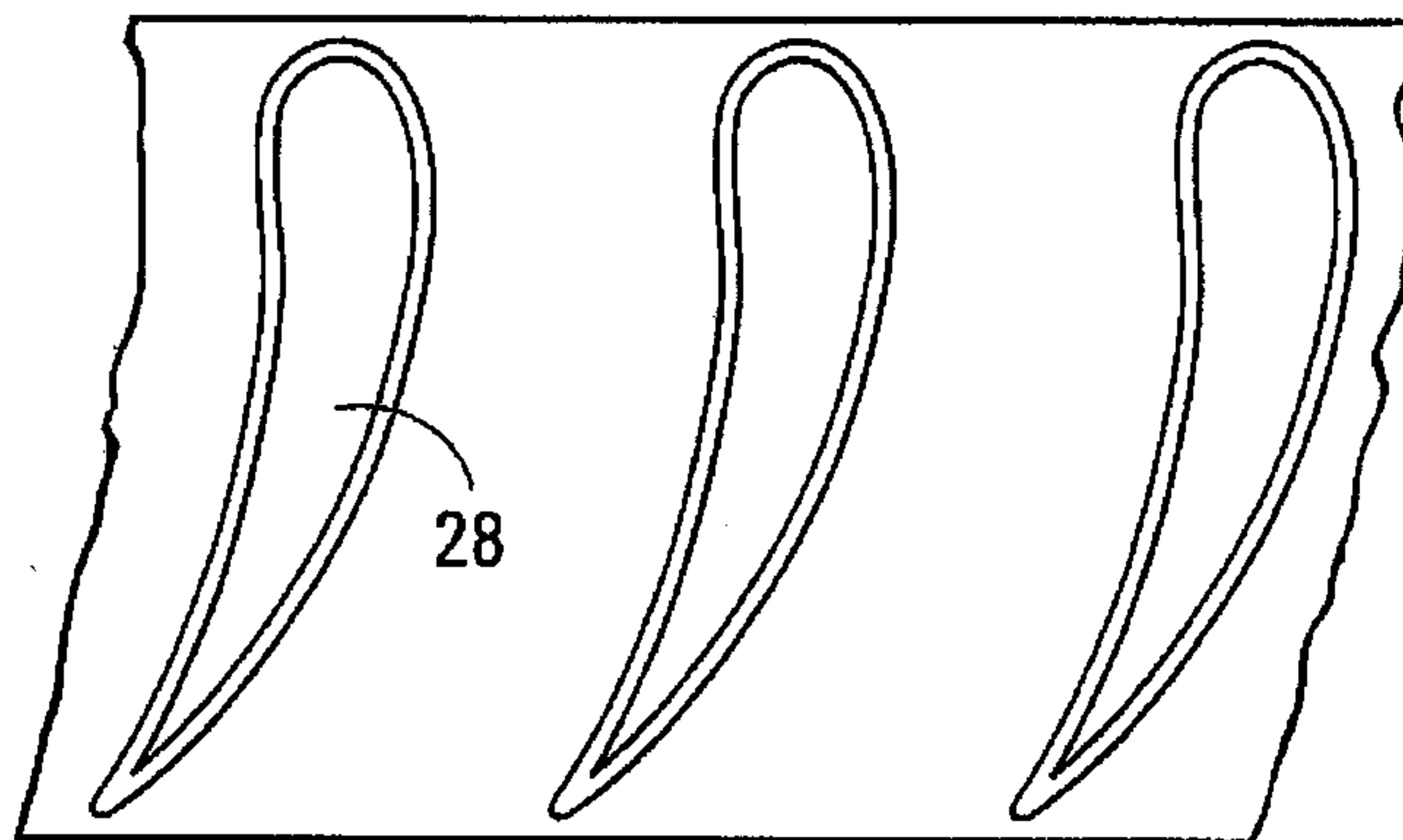


FIG. 2B

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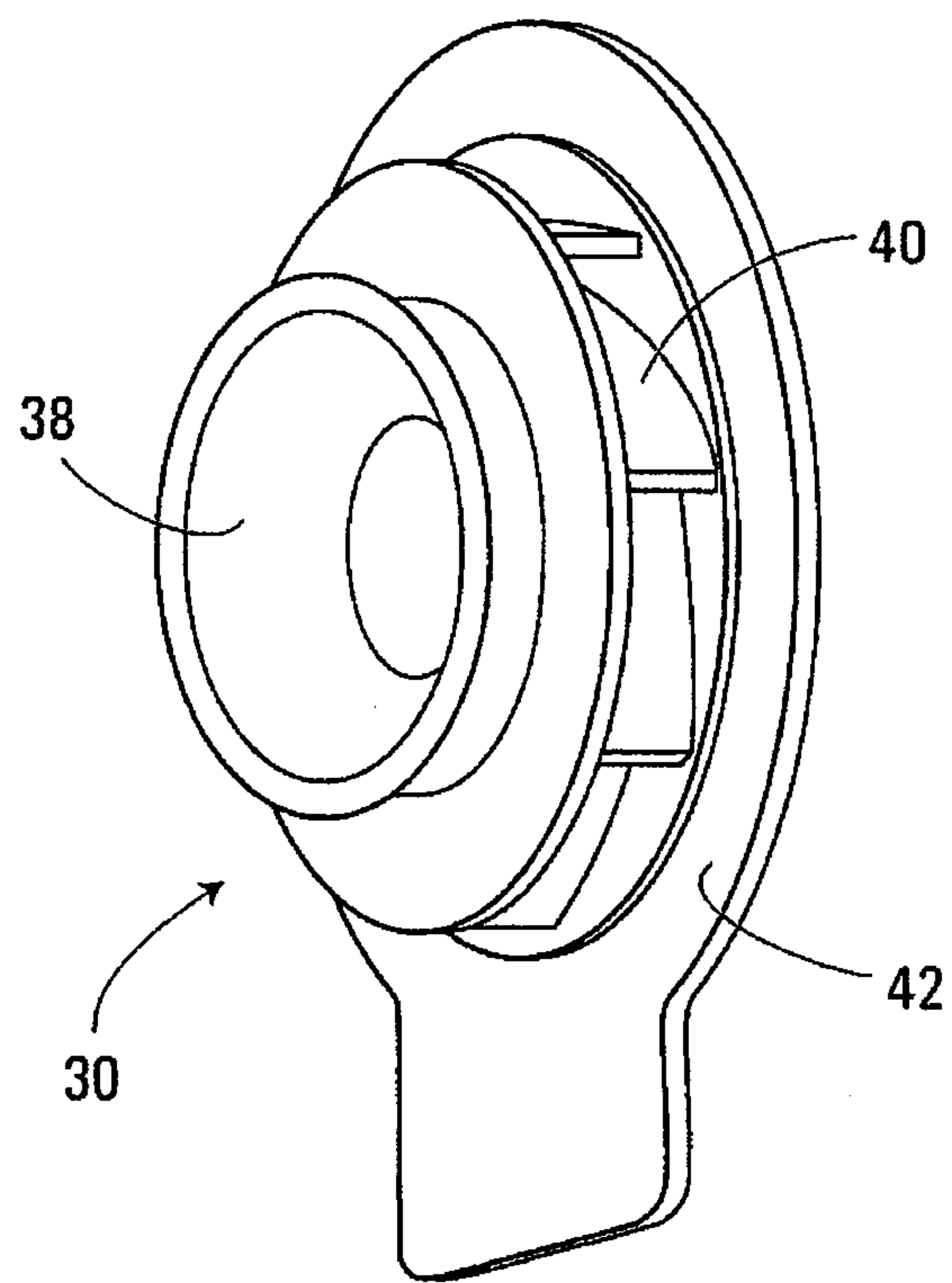


FIG. 3

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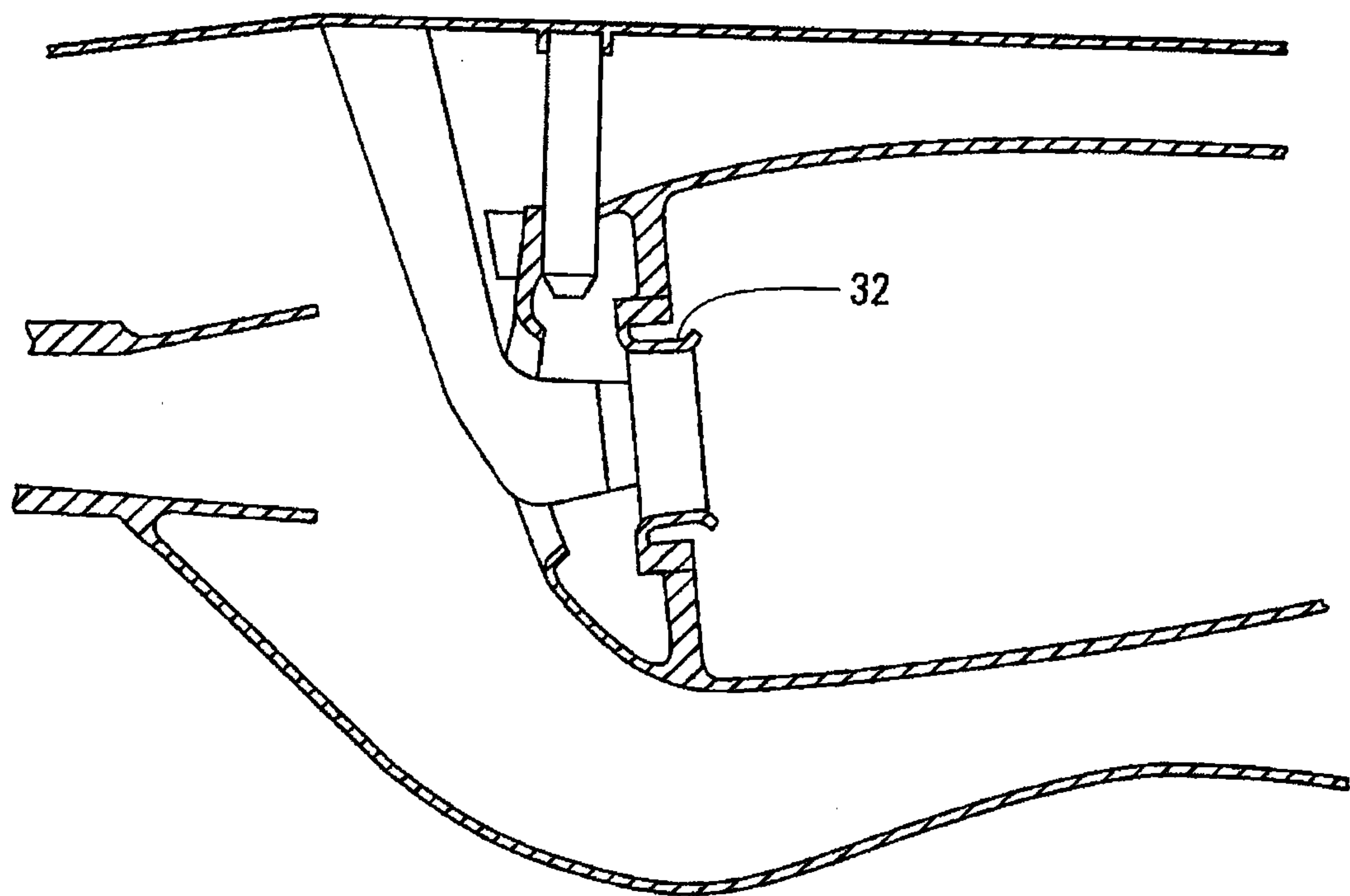


FIG. 4

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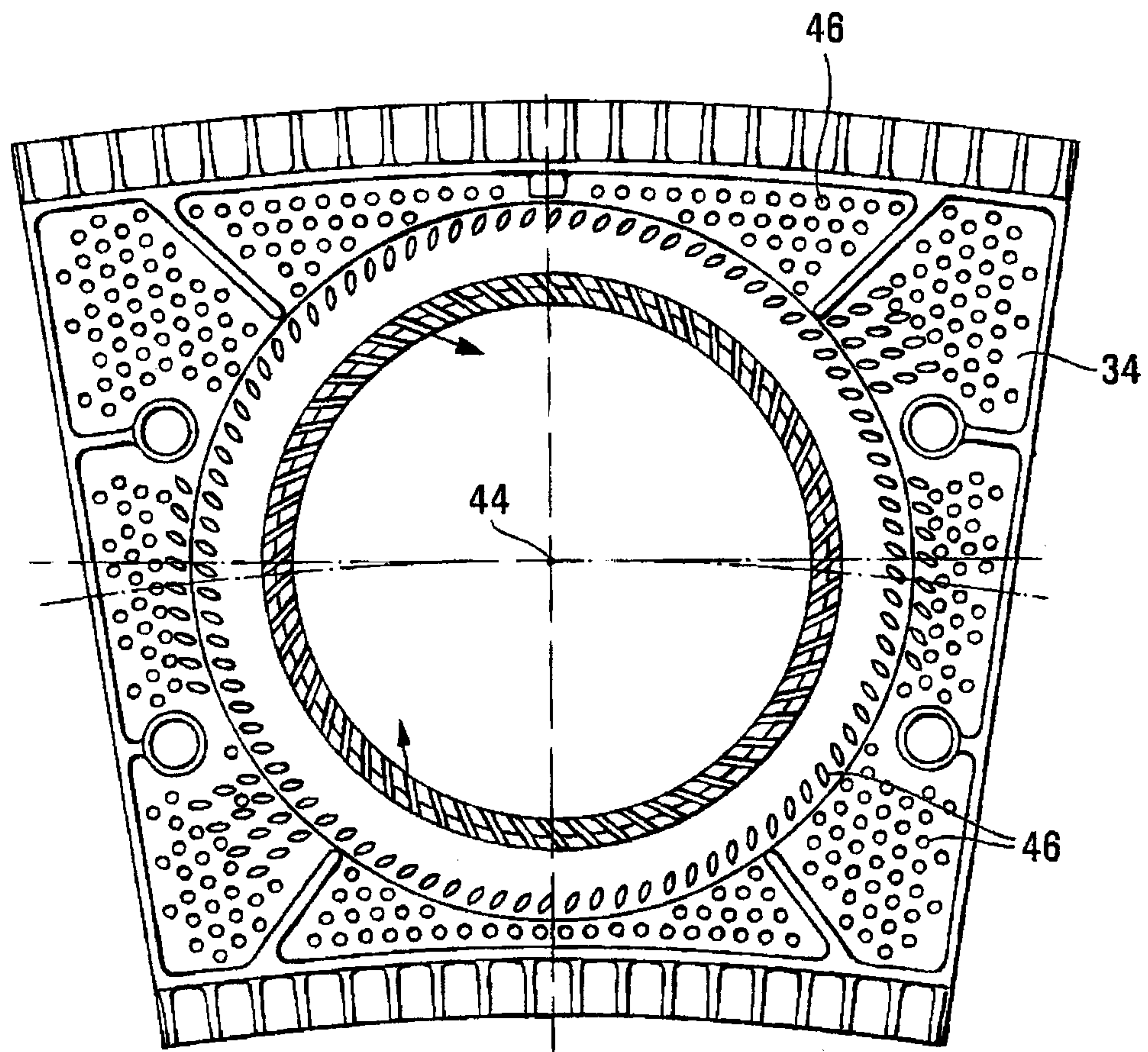


FIG. 5

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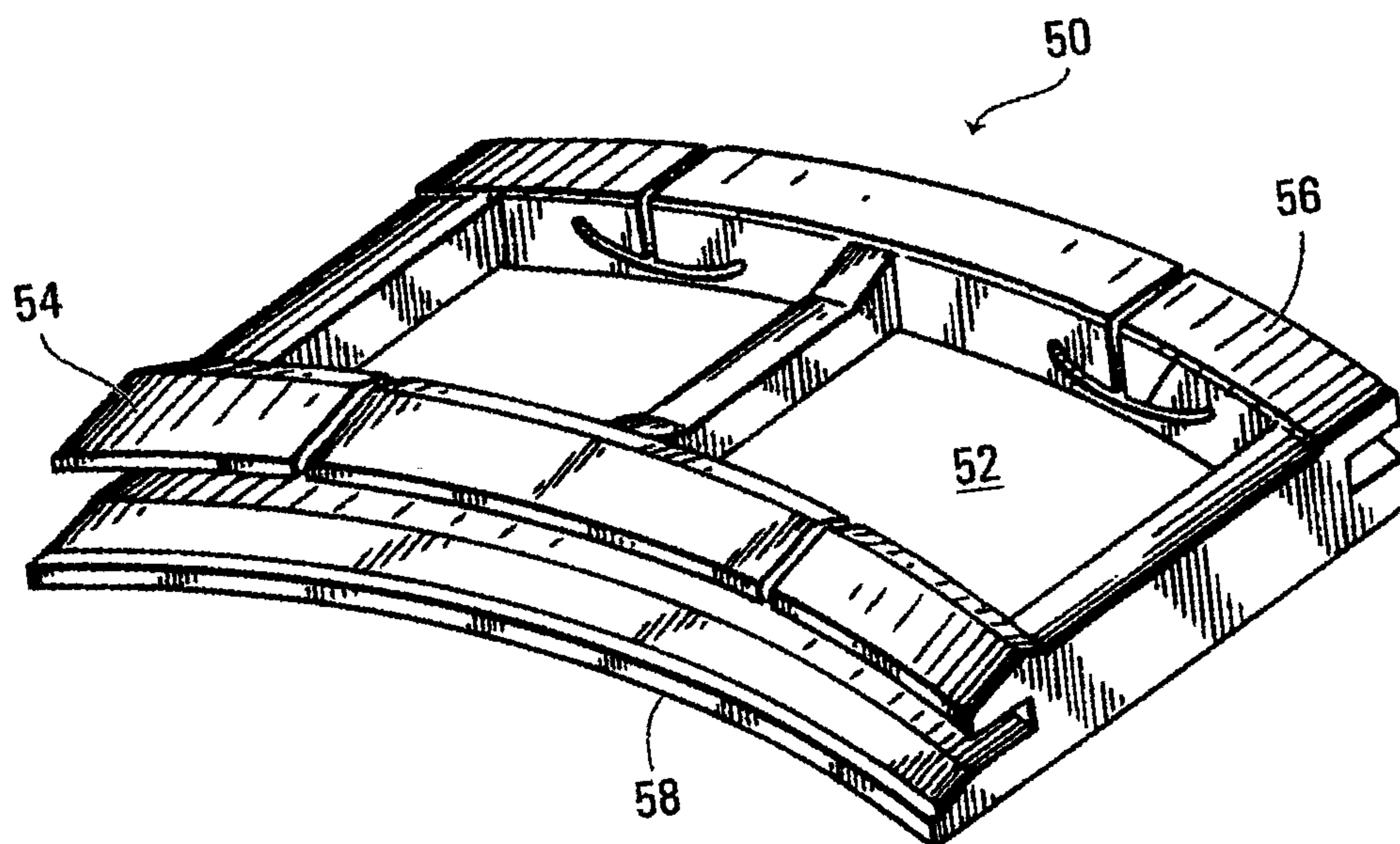


FIG. 6

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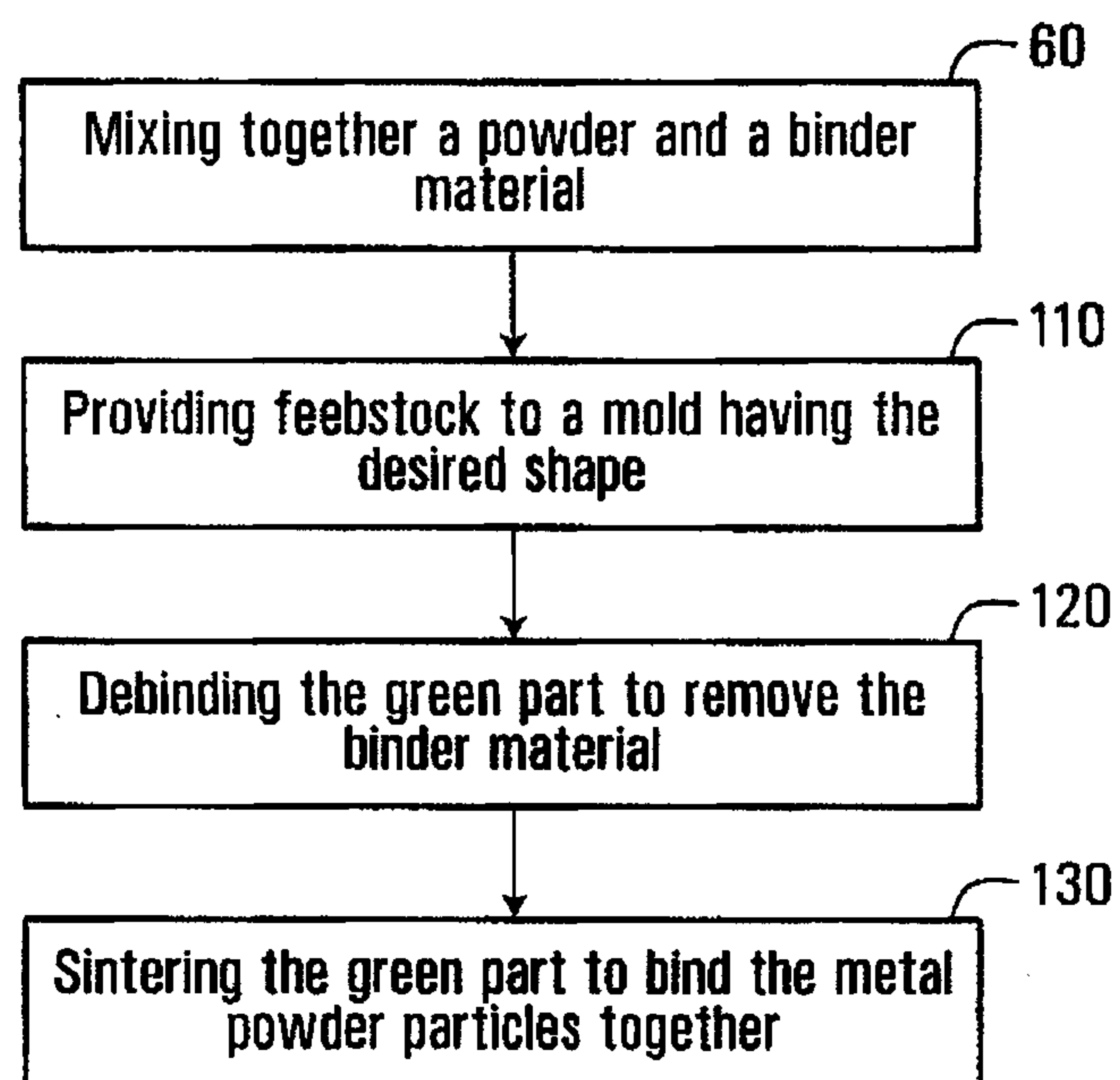


FIG. 7

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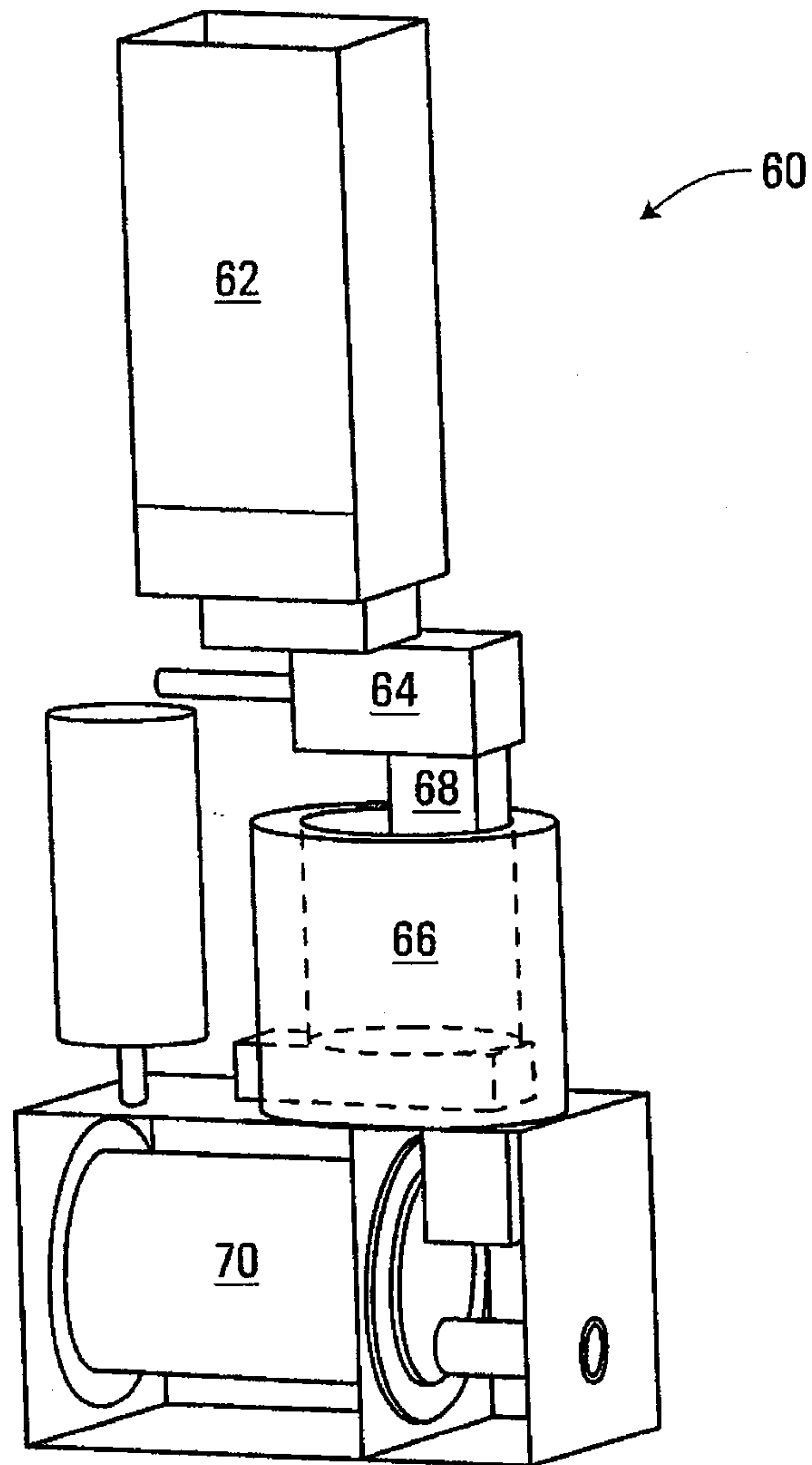


FIG. 8

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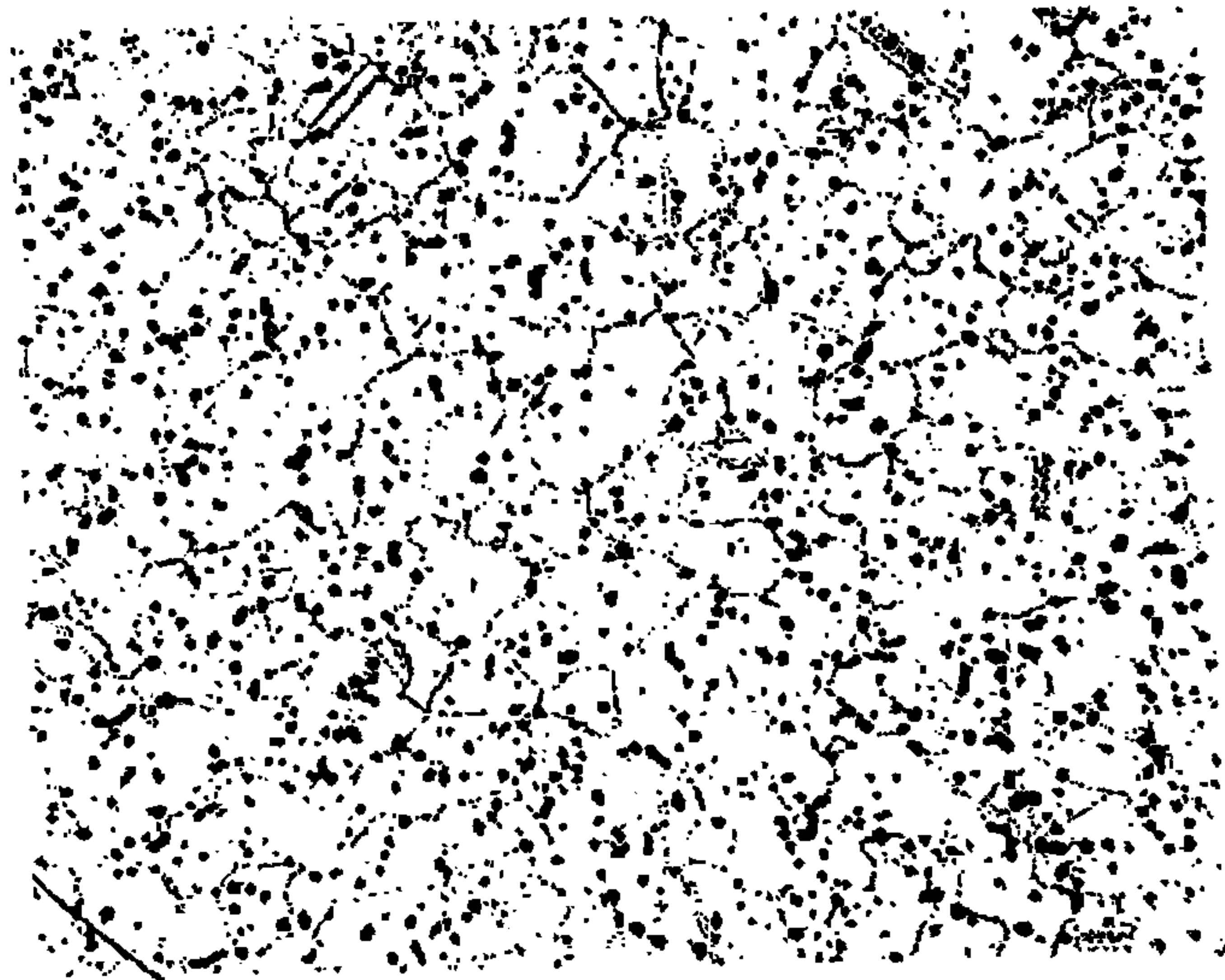


FIG. 9

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