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(54) A CORE FOR AN INVESTMENT CASTING PROCESS

(57) A core (400) for an investment casting process in which a component to be cast has an internal passageway, the internal passageway being provided by the core (400), the core (400) comprising: a first core passage (401) having a first point (405) and a second point (406) therein and including no straight path between the first point (405) and the second (406); and a first core bridge (421a) which extends away from the first core passage (401) between the first and second points (405, 406), wherein the first core bridge (421a) comprises a first pillar (422) and a second pillar (412a) which connect to the first and second points (405, 406) respectively, and a bridge portion (423a) which extends between the first and second pillars (422, 412a); wherein the first pillar (422) comprises a core inlet portion (408) having a thickness at the first point (405) and the second pillar (412a) has a thickness at the second point (406), the thickness of the core inlet portion (408) at the first point (405) being less than the thickness of the second pillar (412a) at the second point (406).

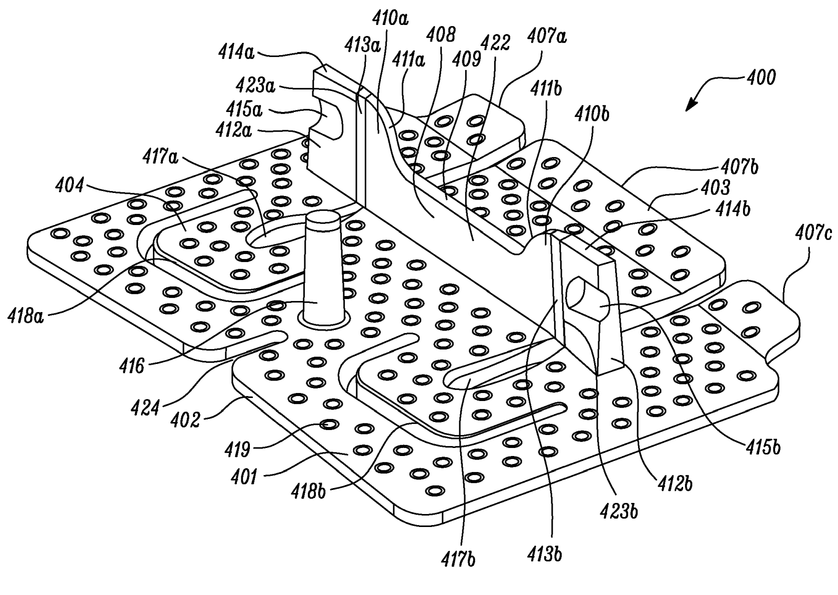

FIG. 4

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Description

[0001] The present disclosure concerns a method for providing core stability for cores of an investment casting process. The disclosure relates to an investment casting core for a component having internal passages which require high precision positioning.

[0002] Figure 1 shows a ducted fan gas turbine engine 10 comprising, in axial flow series: an air intake 12, a propulsive fan 14 having a plurality of fan blades 16, an intermediate-pressure compressor 18, a high-pressure compressor 20, a combustor 22, a high-pressure turbine 24, an intermediate-pressure turbine 26, a low-pressure turbine 28 and a core exhaust nozzle 30. The fan, compressors and turbines are all rotatable about a principal axis 31 of the engine 10. A nacelle 32 generally surrounds the engine 10 and defines the intake 12, a bypass duct 34 and a bypass exhaust nozzle 36.

[0003] Air entering the intake 12 is accelerated by the fan 14 to produce a bypass flow and a core flow. The bypass flow travels down the bypass duct 34 and exits the bypass exhaust nozzle 36 to provide the majority of the propulsive thrust produced by the engine 10. The core flow enters in axial flow series the intermediate-pressure compressor 18, high-pressure compressor 20 and the combustor 22, where fuel is added to the compressed air and the mixture burnt. The hot combustion products expand through and drive the high-, intermediate- and low-pressure turbines 24, 26, 28 before being exhausted through the nozzle 30 to provide additional propulsive thrust. The high-, intermediate- and low-pressure turbines 24, 26, 28 respectively drive the high- and intermediate-pressure compressors 20, 18 and the fan 14 by interconnecting shafts 38, 40, 42.

[0004] The performance of gas turbine engines, whether measured in terms of efficiency or specific output, is generally improved by increasing the turbine gas temperature. It is therefore desirable to operate the turbines at the highest possible temperatures. As a result, the turbines in state of the art engines, particularly high-pressure turbines, operate at temperatures which are greater than the melting point of the material of the blades and vanes making some form cooling necessary.

[0005] Typically, components are cooled by a flow of compressed air which is at a higher pressure than the main gas path but a significantly lower temperature. Components are provided with internal cooling passages which both distribute the cooling air and act to internally cool a particular component.

[0006] A continuing challenge of providing cooling passages within components is to improve the tolerance with which the passages can be placed within components so that the wall thickness of a component can be reduced so far as possible.

[0007] Typically, cooling passages can be provided by so-called lost wax method or investment casting of components as is well known in the art of casting technology. Lost wax casting involves the principal steps of forming a ceramic core, surrounding the core with a wax (or other suitable sacrificial material), prior to coating the waxed core with a ceramic shell. The core defines an internal cavity within the cast metal component, the wax defines the space in which metal will be cast, and the shell defines the external surface of the cast metal component.

[0008] The core may be injection moulded prior to consolidation by drying and optionally firing. The core is then placed in a second mould and wax is injected. The wax covered core is then repeatedly dipped in ceramic slurry to provide the shell. Once the shell is dry, the wax is removed using the appropriate process as defined by the chemistry of the wax (e.g. by soaking in water for a water soluble wax, or heating) and the vacated mould fired to ready it for receiving molten metal. To cast the object, metal is poured into the cavity which has been provided by the removed wax. After the metal has solidified, the ceramic parts are removed by a leaching process to leave the cast metal component which may be further processed by machining or annealing for example.

[0009] Known problems with ceramic cores include the inevitable shrinkage and warping during the drying and firing thereof, and the wax encapsulation which may involve a high pressure injection with resultant mechanical stresses on the core parts. Thus, in any core production there will be a manufacturing tolerance which must be accommodated.

[0010] One effect of providing this tolerance is the addition of material to the walls of the cast component so as to guarantee a minimum wall thickness after any movement or shrinkage is allowed for. However, providing a minimum wall thickness may be problematic where the wall thickness needs to be as low as possible, for example, to reduce the component weight or allowing the performance of the resultant cast component to be as predictable as possible.

[0011] The straying of core sections away from an expected or desired position is more notable for longer core passages in which there is an accumulation of error along the length of the passage and the elongate geometry results in an inherently more flexible structure which is less able to withstand the wax injection or subsequent processing steps without drifting from the required position.

[0012] The movement of sections of a core is most notable when a relatively long core section is tortuous such that the passage length between two points is significantly greater than the direct separation between the two points. Thus, the movement accumulated over the length is presented across a smaller separation.

[0013] One way to combat relative movement between core passages is to use so-called core ties which extend between adjacent core passages and provide some stability. These core ties may be ceramic, and thus form part of the cooling passage once the ceramic has been removed. This leads to the addition of a potentially unwanted cooling path joining adjacent passages which short circuits some of the cooling circuit.

[0014] Another method of providing core stability is to use metallic core ties which are subsumed into the cast metal part due to the relative melting point of the ties and liquid metal used to cast the part.

[0015] Both of these methods are suitable for particular core passage geometries, but are lacking for others.

[0016] EP3064290A1 describes a core for an investment casting process, comprising: a core passage which extends between a first point and a second point along a tortuous path having length L, wherein the first point and second point are separated by a direct line of sight distance, S, wherein L is greater than S; and, a core bridge which extends between the first and second points away from the core passage.

[0017] The disclosure seeks to provide an improved core structure and method of casting a component which allows for more accurate placement of the cooling passages to allow for improved components with more predictable cooling properties and the potential for reducing the wall thickness of component.

[0018] According to a first aspect there is provided a core for an investment casting process in which a component to be cast has an internal passageway, the internal passageway being provided by the core, the core comprising: a first core passage having a first point and a second point therein and including no straight path between the first point and the second point; and a first core bridge which extends away from the first core passage between the first and second points, wherein the first core bridge comprises a first pillar and a second pillar which connect to the first and second points respectively, and a bridge portion which extends between the first and second pillars; wherein the first pillar comprises a core inlet portion having a thickness at the first point and the second pillar has a thickness at the second point, the thickness of the core inlet portion at the first point being less than the thickness of the second pillar at the second point.

[0019] The core inlet portion may have a height H1 at the first point and the second pillar may have a height H2 at the second point. H1 may be less than H2.

[0020] The first core passage may include a tortuous path between the first point and the second point. The first core passage may include more than one tortuous path between the first point and the second point.

[0021] The first core passage may include a first path extending away from the first point and a second path extending away from the second point.

[0022] The first and/or second pillars may extend away from the first core passage in a perpendicular direction at either or both of the first and second points. The first and/or second pillars may extend away from the first core passage in a non-perpendicular direction, e.g. at an angle of up to 30°, up to 20°, up to 10° or up to 5° from the perpendicular direction. The first and/or second pillars may extend away from the first core passage at an angle of at least 1° or at least 3° from the perpendicular.

[0023] The first and second pillars may extend away from the core passage in a common direction. The common direction may be defined by the longitudinal axis of each pillar. Alternatively, or additionally, the common direction may be defined as being towards an exterior wall region of the core. The exterior wall region of the core will be defined by a component cast from the core and or when the core is surrounded by a sacrificial layer such as wax.

[0024] The first core passage may be disposed in a plane. The plane may be curved in at least one dimension.

[0025] The first core passage may lie within a plane and the core bridge extends out of that plane. The common plane may be curved in at least one dimension. The plane may be defined by the first and second connection points and the portion of the first core passage which is furthest from the first and second connection points.

[0026] The core may comprise a ceramic material. The core may further comprise an outer layer of a sacrificial material. The outer surface of the sacrificial material may define the interior surface of an externally facing wall of a cast component. The sacrificial material may be wax-based. The core may further comprise a ceramic shell. The ceramic shell may encapsulate the sacrificial layer and provide a containment wall for receiving a molten metal from which the cast component is made.

[0027] The first core bridge may extend between the core passage and the shell. The bridge portion may be at least partially, e.g. fully, encased within the ceramic shell.

[0028] The core inlet portion provides an inlet to the first core passage.

[0029] The first point may be located anywhere along a length and/or across a width of the core inlet portion and/or the first pillar. For example, the first point may be located in a central portion of, e.g. midway along, a length of the core inlet portion.

[0030] The second point may be located anywhere along a length and/or across a width of the second pillar. For example, the second point may be located in a central portion of, e.g. midway along, a length of the second pillar.

[0031] The first core bridge may comprise a transition region between the core inlet portion and the second pillar. The transition region may be part of the first pillar, the bridge portion and/or the second pillar

[0032] The transition region may comprise a sloping upper surface, which connects an upper surface of the core inlet portion to an upper surface of the second pillar. The sloping upper surface may be curved at least in part.

[0033] The second pillar may have at least one side wall. The side wall(s) of the second pillar may be vertical. The side wall(s) of the second pillar may be oriented at an angle of up to 45° from vertical, up to 30° from vertical, up to 15° from vertical, up to 10° from vertical or up to 5° from vertical. The side wall(s) of the second pillar may be oriented at an angle of at least 1° from vertical or up to or at least 3° from vertical. The side wall(s) of the second pillar may be sloping and/or curved at least in part. The second pillar may have a pair of opposing side walls. The pair of opposing side walls of the second pillar may or may not be parallel.

[0034] The first pillar may have at least one side wall. The side wall(s) of the first pillar may be vertical. The side wall(s) of the first pillar may be oriented at an angle of up to 45° from vertical, up to 30° from vertical, up to 15° from vertical, up to 10° from vertical or up to 5° from vertical. The side wall(s) of the first pillar may be oriented at an angle of at least 1° from vertical or up to or at least 3° from vertical. The side wall(s) of the first pillar may be sloping and/or curved at least in part. The first pillar may have a pair of opposing side walls. The pair of opposing side walls of the first pillar may or may not be parallel.

[0035] The core inlet portion may have at least one side wall. The side wall(s) of the core inlet portion may be vertical. The side wall(s) of the core inlet portion may be oriented at an angle of up to 45° from vertical, up to 30° from vertical, up to 15° from vertical up to 10° from vertical or up to 5° from vertical. The side wall(s) of the second pillar may be oriented at an angle of at least 1° from vertical or up to or at least 3° from vertical. The side wall(s) of the core inlet portion may be sloping and/or curved at least in part. The core inlet portion may have a pair of opposing side walls. The pair of opposing side walls of the core inlet portion may or may not be parallel.

[0036] The core inlet portion may comprise at least one indent, groove or recess. The or each indent, groove or recess may extend in a transverse direction at least partially across a side wall of the core inlet portion.

[0037] In embodiments in which the thickness of the core inlet portion at the first point is less than the thickness of the second pillar at the second point, the transition region may comprise one or more transition region side walls connecting one of the side walls of the core inlet portion to one of the side walls of the second pillar. A given transition region side wall may not be perpendicular to the side wall of the core inlet portion and/or the side wall of the second pillar that are connected by the given transition region side wall. A given transition region side wall may be oriented at an angle of at least 10° and/or up to 80° relative to the side wall of the core inlet portion and/or the side wall of the second pillar that are connected by the given transition region side wall. A given transition region side wall may be curved at least in part.

[0038] The core may comprise one or more shell lock features. The shell lock feature(s) may be provided in the second pillar. The shell lock feature(s) may each comprise a groove, a recess or a notch.

[0039] The core may comprise more than one core bridge. The core may comprise any number of further core bridges, e.g. a second core bridge, a third core bridge and/or a fourth core bridge. Each further core bridge may comprise a first pillar, a second pillar and a bridge portion extending between the first and second pillars.

[0040] One or more of the core bridges may serve to hold the core in the correct position during the casting process.

[0041] The first pillar of a given further core bridge may comprise a core inlet portion, which may be of a lower height than the second pillar of the given further core bridge.

[0042] The core inlet portion may be common to more than one core bridge.

[0043] The bridge portion(s) may have a length of up to or at least 1 mm, up to or at least 2 mm, up to or at least 5 mm, up to or at least 10 mm or up to or at least 20 mm.

[0044] The core may comprise more than one core passage. The core may comprise any number of further core passages, e.g. a second core passage, a third core passage, a fourth core passage and so on.

[0045] The tortuous path may have a length L and the first point and the second point may be separated by a direct line of sight distance S, wherein L is greater than S. The direct line of sight distance S may be at least 1 mm, up to or at least 2 mm, up to or at least 5 mm or up to or at least 10 mm. The direct line of sight distance S will be at least as long as the bridge portion.

[0046] The ratio of L:S may be up to or at least 2:1, up to or at least 5:1, up to or at least 10:1 or up to or at least 12:1. The ratio of L:S may be up to or at least 20:1, up to or at least 50:1 or up to or at least 80:1. The ratio of L:S may be up to 200:1, up to 400:1 or up to 500:1.

[0047] The core may be used to provide at least one cooling passage for a gas turbine engine. The cooling passage(s) may have an inlet and an outlet to introduce and exhaust a flow of cooling fluid, e.g. air. The inlet of the first cooling passage may be provided by the connection of the first pillar of the first core bridge at the first point. The inlet of the first cooling passage may be provided by the core inlet portion.

[0048] The core may be used to provide a cast component. The cast component may comprise, or consist essentially of, an alloy such as a nickel alloy or an aluminium alloy. The alloy may be present as a single crystal. The cast component may be a component for a gas turbine engine. The component may be a fluid-cooled, e.g. air-cooled, component having at least one cooling passage for a flow of fluid, e.g. air, provided by the core. The component may be a seal segment for bounding a portion of a main gas path of a gas turbine engine. The component may be a combustion tile.

[0049] A second aspect provides a ceramic shell for an investment casting process in which a component to be cast has at least one internal passageway, the internal passageway(s) being provided by a core, the ceramic shell comprising: a core according to the first aspect, the core having an outer layer of a sacrificial material within the ceramic shell, wherein the first core bridge extends between the first core passage and the ceramic shell through the sacrificial material.

[0050] The first core bridge may serve to hold the core in the correct position during the casting process.

[0051] The component to be cast may have at least one exterior wall.

[0052] The sacrificial material may be wax-based.

[0053] A third aspect provides a cast component comprising: at least one internal passageway formed by a core of the first aspect, the cast component having an aperture to the internal passageway at a first point and a cap sealing an aperture at a second point, , wherein the apertures at the first and second points respectively correspond to the connections of the core inlet portion and second pillar provided by the core.

[0054] The cast component may comprise one or more further caps sealing apertures at one or more further points.

[0055] The cast component may be a seal segment for bounding a portion of a main gas path of a gas turbine engine. The cast component may be a combustion tile.

[0056] The at least one internal passageway may have a local area contraction corresponding to an indent, groove or recess on the core.

[0057] A fourth aspect provides a gas turbine engine comprising a cast component of the third aspect.

[0058] A method for casting a component may comprise: providing a ceramic shell as described above; removing the sacrificial material; pouring molten metal into a cavity created by the removal of the sacrificial material.

[0059] The molten metal may comprise, or consist essentially of, an alloy such as a nickel alloy or an aluminium alloy. In a cast component manufactured using the method, the metal may be present as a single crystal.

[0060] The core may be injection moulded from a ceramic material prior to solidification and drying. The method may further comprise removing the ceramic shell and core, wherein the first point is provided as an inlet for the passageway within the component and the second point is sealed over with a cap.

[0061] The skilled person will appreciate that except where mutually exclusive, a feature described in relation to any one of the above aspects may be applied mutatis mutandis to any other aspect. Furthermore except where mutually exclusive any feature described herein may be applied to any aspect and/or combined with any other feature described herein.

[0062] Embodiments will now be described by way of example only, with reference to the Figures, in which:

Figure 1 is a sectional side view of a gas turbine engine;

Figure 2 shows a cross section of a turbine shroud arrangement;

Figure 3 is a side view of a core for use in casting a component containing one or more internal passageways.

Figure 4 is a perspective view of another core for use in casting a component containing one or more internal passageways;

Figure 5 is a plan view of the core shown in Figure 4;

Figure 6 is an end elevation of the core shown in Figure 4 and Figure 5; and

Figure 7 shows a cast component.

[0063] Figure 2 provides a cross-section of a shroud arrangement 210 and surrounding structure which can be located within the architecture of a substantially conventional gas turbine engine, e.g. as illustrated in Figure 1. Other gas turbine engines to which the present disclosure may be applied may have alternative configurations. By way of example such engines may have an alternative number of interconnecting shafts (e.g. two) and/or an alternative number of compressors and/or turbines. Further the engine may comprise a gearbox provided in the drive train from a turbine to a compressor and/or fan.

[0064] The shroud arrangement 210 forms part of the turbine section of a gas turbine engine similar to that shown in Figure 1 and defines the boundary of the hot gas flow path 211 thereby helping to prevent gas leakage and provide thermal shielding for the outboard structures of the turbine.

[0065] The turbine (rotor) blade 212 sits radially inwards of the shroud arrangement 210 and is one of a plurality of conventional radially extending blades which are arranged circumferentially around a supporting disc (not shown) which is rotatable about the principal axis 31 (Figure 1) of the engine. Corresponding arrays of nozzle guide vanes 214a, 214b, are axially offset from the rotor blades 212 with respect to the principal axis 31 (Figure 1) of the engine 10 (Figure 1) and alter the direction of the upstream gas flow such that it is incident on the rotor blades 212 at an optimum angle. Thus, the turbine generally consists of an axial series of nozzle guide vanes 214a and rotor blade 212 pairs arranged along the gas flow path 211 of the turbine, with different pairs being associated with each of the high pressure turbine (HPT), intermediate pressure turbine (IPT) and low pressure turbine (LPT). A given turbine may have more than one nozzle guide vane and rotor blade pairs associated therewith.

[0066] The shroud arrangement 210 shown in Figure 2 principally includes three main parts: a seal segment 216, a carrier segment 218 and an engine casing 220 which sit in radial series outside of the main gas path 211 and rotor blade 212. The shroud arrangement 210 of the embodiment is that of an high pressure turbine, but the disclosure may be applied to other areas of the turbine, or indeed other non-turbine applications where appropriate.

[0067] The seal segment 216 includes a plate 222 having an inboard gas path facing surface 224 and an outboard surface 226 which is provided by the radially outward surfaces of the plate 222 relative to the principal axis 31 of the engine 10. The seal segment 216 is one of an array of similar segments which are linked so as to provide an annular shroud which resides immediately radially outwards of the turbine rotor blades 212 and defines the radially outer wall of the main gas flow path 211. Thus, the seal segment 216 shown is one of a plurality of similar arcuate segments which circumferentially abut one another to provide a substantially continuous protective structure around the rotor blade 212 tip path.

[0068] The seal segment 216 is fixed to the engine casing 220 via a corresponding carrier segment 218. The carrier segment 218 is one of a plurality of segments which join end to end circumferentially to provide an annular structure which is coaxial with the principal axis 31 of the engine. The engine casing 220 is a full annular housing which sits outboard of the carrier 218 and generally provides structural support and containment for the turbine components, including providing direct support for the shroud cassette which comprises the seal segment and carrier 218.

[0069] The seal segment 216 is contacted by the hot gas flow through the turbine and thus requires cooling fluid, e.g. air. The choice of cooling fluid, e.g. air, source is largely dictated by the required reduction in temperature at a particular location and the expected working pressure the cooling fluid, e.g. air, exhausts into.

[0070] The cooling fluid, e.g. air, can be provided from any suitable source. The cooling fluid, e.g. air, may be provided in the form of bleed air from one or more compressor stages. Thus, air may be bled from the compressor and passed through various air cooling circuits both internally and externally of the components to provide the desired level of cooling.

[0071] To provide suitable cooling to the seal segment, internal passageways are provided in the plate 222 which channel cooling fluid, e.g. air, through the component prior to being exhausted ultimately into the main gas path.

[0072] Figure 3 is a side view of a core 300 for use in casting a component containing one or more internal passageways. The component may comprise a seal segment or a combustion tile for use in a gas turbine engine. The core 300 provides the internal passageway(s) of the cast component.

[0073] Very generally, the core 300 is moulded from a ceramic material which is subsequently coated in wax prior to being encased in a ceramic shell. The wax is then removed and molten metal poured into the ceramic shell and the vacancy left by the wax. The core 300 and shell are then removed to provide a hollow metal cast part with an internal passageway (or passageways) corresponding to the shape of the core 300.

[0074] The core 300 comprises a chimney portion 301 and a core passage 302. The chimney portion 301 extends away from the core passage 302. The chimney portion 301 is perpendicular to the core passage 302. The chimney portion 301 extends away from the core passage 302 such that it can pass through the sacrificial layer, e.g. wax, once applied, and connect with the ceramic shell. In so doing, the chimney portion 301 extends away from the core passage 302 through an exterior wall of the component once cast, so as to leave a hole in an exterior-facing surface. The chimney portion 301 serves to hold the core 300 in the correct position during the casting process.

[0075] The core passage 302 extends from an upstream end 303 to a downstream end 304. The chimney portion 301 connects with the core passage 302 at an intermediate location between the upstream end 303 and the downstream end 304. A base 307 of the core passage 302 extends from the upstream end 303 to the downstream end 304.

[0076] The core passage 302 may be considered generally planar. The chimney portion 301 can thus be thought of as extending out of a plane defined at least in part by the core passage 302. It will be appreciated that the plane may be a circumferential plane in the example of the cast component being a seal segment for use in a gas turbine engine, due to the seal segment forming part of an annular wall. Hence, the plane may be curved. Thus, the chimney portion 301 may extend out relative to the tangential plane in the immediate vicinity of the point at which it connects with the core passage 302. However, it will also be appreciated that a core passage may extend along a curved or stepped path having different radii of curvature and relative height levels, in which a satisfactory definition of a plane cannot be obtained.

[0077] The chimney portion 301 and the core passage 302 each form an internal passageway in the cast component. The formed internal passageways communicate with each other to provide a continuous internal passageway from an inlet corresponding to at least a portion of an end 306 of the chimney portion 301 distal from the core passage 302 to an outlet corresponding to at least a portion of the downstream end 304 of the core passage 302.

[0078] The chimney portion 301 comprises a groove 306, which extends in a transverse direction across the chimney portion 301. The groove 306 is disposed relatively close to the core passage 302. The groove 306 provides a local area contraction in the passageway in the cast component. The local area contraction acts to generate an impingement cooling enhancement, as cooling fluid, e.g. air, passes along the internal passageway from the inlet to the outlet. The local area contraction causes an increase in the pressure of the cooling fluid, which then accelerates as it exits the local area contraction. The accelerated cooling fluid impinges on a hot surface of the cast component corresponding to the base 307 of the cooling passage 302. The accelerated cooling fluid has increased momentum, thereby enhancing the impingement cooling. The chimney portion may comprise more than one groove, e.g. a pair of grooves on opposite sides of the chimney portion. It will be appreciated that the groove is simply an example of a suitable feature for providing a local area contraction. One or more other features that provide a local area contraction such as indents or recesses may be present instead of or as well as a groove.

[0079] Figures 4, 5 and 6 show another example of a core 400 for use in casting a component containing one or more internal passageways. The component may comprise a seal segment or a combustion tile for use in a gas turbine engine. The core 400 provides the internal passageway(s) of the cast component.

[0080] Very generally, the core 400 is moulded from a ceramic material which is subsequently coated in wax prior to being encased in a ceramic shell. The wax is then removed and molten metal poured into the ceramic shell and the vacancy left by the wax. The core 400 and shell are then removed to provide a hollow metal cast part with an internal passageway (or passageways) corresponding to the shape of the core 400.

[0081] The core 400 comprises a core passage 401. The core passage 401 has an upstream end 402 and a downstream end 403.

[0082] The core passage 401 may be considered generally planar. It will be appreciated that the plane may be a circumferential plane in the example of the cast component being a seal segment for use in a gas turbine engine, due to the seal segment forming part of an annular wall. Hence, the plane may be curved. However, it will also be appreciated that a core passage may extend along a curved or stepped path having different radii of curvature and relative height levels, in which a satisfactory definition of a plane cannot be obtained.

[0083] Within the core passage 401, a first cooling passage 404 includes a first point 405 and a second point 406 and has a tortuous path 420 between the first point 405 and the second point 406. The first point 405 and the second point 406 are separated by a direct line of sight distance S and tortuous path 420 has a length L. L is greater than S.

[0084] The core 400 comprises a first core bridge 421a extending away from the core passage 401. The first core bridge 421a comprises a first pillar 422, a second pillar 412a and a bridge portion 423a extending between the first pillar 422 and the second pillar 412a. The first pillar 422 comprises a core inlet portion 408. The core inlet portion 408 has a height H1 at the first point 405. The second pillar 412a has a height H2 at the second point 406. H1 is less than H2.

[0085] The first point 405 may be considered to be at any point in the core passage 401 underneath the first pillar 422 and/or the core inlet portion 408. The second point 406 may be considered to be at any point in the core passage 401 underneath the second pillar 412a. Wherever the first point 405 and the second point 406 are located, there is no straight path within the core passage 401 from the first point 405 to the second point 406. The direct line of sight distance S will be at least as long as the bridge portion 423a.

[0086] The first core bridge 421a comprises a transition region 410a. The transition region 410a has a curved upper surface 411a. The curved upper surface 411a connects an upper surface 409 of the core inlet portion 408 to an upper surface 414a of the second pillar 412a.

[0087] The second pillar 412a is thicker than the core inlet portion 408. The transition region 410a includes a pair of transition region side walls 413a, 413a'. The transition region side walls 413a, 413a' are disposed on opposite sides of the first core bridge 421a. The transition region side walls 413a, 413a' each connect a side wall of the first pillar 422 to a side wall of the second pillar 412a.

[0088] The first core bridge 421a comprises a shell lock feature 415a. The shell lock feature 415a has the form of a groove. The shell lock feature 415a extends partially across a side wall of the second pillar 412a. The shell lock feature 415a may be machined into the core 400.

[0089] The core 400 further comprises a second core bridge 421b extending away from the core passage 401. The second core bridge 421b comprises the first pillar 422, which the second core bridge 421b shares with the first core bridge 421a, a second pillar 412b and a bridge portion 423b extending between the first pillar 422 and the second pillar 412a. The second pillar 412b is taller than the first pillar 422.

[0090] The second core bridge 421b comprises a transition region 410b. The transition region 410b has a curved upper surface 411b. The curved upper surface 411b connects the upper surface 409 of the core inlet portion 408 to an upper surface 414b of the second pillar 412b.

[0091] The second pillar 412b is thicker than the core inlet portion 408. The transition region 410b includes a pair of transition region side walls 413b, 413b'. The transition region side walls 413b, 413b' are disposed on opposite sides of the second core bridge 421b. The transition region side walls 413a, 413a' each connect a side wall of the first pillar 422 to a side wall of the second pillar 412a.

[0092] The second core bridge 421b comprises a shell lock feature 415b. The shell lock feature 415b has the form of a groove. The shell lock feature 415b extends partially across a side wall of the second pillar 412b. The shell lock feature 415b may be machined into the core 400.

[0093] The first core bridge 421a and the second core bridge 421b can be thought of as extending out of the plane defined by the core passage 401.

[0094] The second pillars 412a, 412b extend away from the core passage 401 such that they can each pass through the sacrificial layer, e.g. wax, once applied, and connect with the ceramic shell. In so doing, the second pillars 412a, 412b extend away from the core passage, through the component wall once cast, so as to each leave a hole in an exterior facing surface. The core inlet portion 408 also leaves a hole in the exterior facing surface. The hole left by the core inlet portion 408 is less thick than the holes left by the second pillars 412a, 412b.

[0095] It will be appreciated that the relative position of the first and second points with respect to the length of the first cooling passage and/or the core passage, and the span of the or each core bridge, may vary.

[0096] It will be appreciated that other configurations of core bridge(s) may be possible. For example, the core may comprise any number of core bridges. Similarly, one or more of the core bridges may not share a common pillar with one or more other core bridges. The first pillar and/or the second pillar of the or each core bridge may generally be polygonal in transverse cross-section, e.g. rectangular. Alternatively, the first pillar and/or the second pillar of the or each core bridge may be curved at least in part in transverse cross-section.

[0097] The core inlet portion may comprise at least one indent, groove or recess. The or each indent, groove or recess may extend in a transverse direction at least partially across a side wall of the core inlet portion. The indent, groove or recess may provide a local area contraction in the cooling passage of the cast component, which may act to provide enhanced impingement cooling.

[0098] The core passage 401 is symmetrical about a line of symmetry which runs transverse to the core inlet portion 408 midway between the first core bridge 421a and the second core bridge 421b. The line of symmetry passes through the first point 405.

[0099] Located on the line of symmetry, a distance towards the upstream end 402 from the core inlet portion 408, the core 400 comprises a cylindrical pillar 416. The cylindrical pillar 416 extends away from the core passage 401 such that it can each pass through the sacrificial layer, e.g. wax, once applied, and connect with the ceramic shell. In so doing, the cylindrical pillar 416 extends away from the core passage 401, through the component wall once cast, so as to leave a hole in an exterior facing surface. The hole may allow inspection, e.g. visual inspection, of the cast component. The hole may facilitate core removal, e.g. by leaching. The cylindrical pillar 416 may have any transverse cross-section.

[0100] Either side of the line of symmetry, the core passage 401 comprises a pair of c-shaped apertures 418a, 418b. The c-shaped apertures 418a, 418b provide guide vanes in the cooling passage(s) of the cast component. The core passage 401 is shaped to provide a Jennings bend 417a, 417b disposed inwards of each of the guide vanes provided by the c-shaped apertures 418a, 418b

[0101] The core passage 401 includes a plurality of apertures 419 therethrough to provide pedestals to aid heat transfer in the cooling passage(s) of the component. For clarity, only one of the apertures 419 is labelled in Figure 4 and Figure 5. Pedestals are merely an example of a suitable feature for aiding heat transfer in the cooling passage(s) of the component that the core 400, e.g. the core passage 401, may be adapted to provide.

[0102] The core 400 further comprises a core notch 424. The core notch 424 is provided in the upstream end 402 of the core passage 401. The core notch 424 is disposed on the line symmetry, upstream of the cylindrical pillar 416.

[0103] The downstream end 403 has three discrete portions 407a, 407b, 407c, which each correspond to outlets from the cooling passage(s) of the cast component.

[0104] The core passage 401 may include one or more core ties to provide additional support or a particular interconnecting flow between the core passages, if required. The need for core ties may have been reduced, if not eliminated, by the core bridge(s).

[0105] In a cast component manufactured using the core 400, a pressurised cooling fluid, e.g. air, is supplied to an inlet corresponding to the upper surface 409 of the core inlet portion 408. The pressurised cooling fluid then enters the cooling passages corresponding to the core passage 401. The pressurised cooling fluid flows in all directions away from the region at which a chimney formed by the core inlet portion 408 meets the cooling passages formed by the core passage 401. Accordingly, some of the pressurised cooling fluid exits the cooling passages via each of the outlets formed by the three discrete portions 407a, 407b, 407c of the downstream end 403 of the core passage 401.

[0106] Figure 7 shows the exterior of a cast component 700. The cast component 700 was made using the core 400 of Figures 4, 5 and 6. The cast component 700 may be a seal segment for bounding a portion of a main gas path of a gas turbine engine. The component may be a combustion tile. The cast component may comprise, or consist essentially of, an alloy such as a nickel alloy or an aluminium alloy. The alloy may be present as a single crystal.

[0107] The cast component 700 comprises an alloy body 701. The body 701 has an upstream end 707 and a downstream end 706. The body 701 comprises an inlet 702 formed by the core inlet portion 408. The inlet 702 has the form of an elongate slot. A pair of apertures 703, 704 are disposed at either end of the inlet 702. The apertures 703, 704 correspond to the second pillars 412a, 412b of the first and second core bridges 421a, 421b respectively.

[0108] Towards the upstream end 707 of the body 701, in line with a midpoint of the inlet 702, there is an inspection hole 705. The inspection hole 705 was provided by the cylindrical pillar 416.

[0109] The apertures 703, 704 and the inspection hole 705 may each be sealed over with a cap. The caps may be joined to the body 701 using any suitable joining technique, for instance welding.

[0110] The body 701 comprises three outlets (not shown) in the downstream end 706. The three outlets were provided by the three discrete portions 407a, 407b, 407c of the downstream end 403 of the core passage 401. Alternatively or additionally, the outlets may be machined into the body 701 to provide outlets that communicate with the internal passages formed by the three discrete portions 407a, 407b, 407c of the downstream end 403 of the core passage 401.

[0111] It will be understood that the invention is not limited to the embodiments above-described and various modifications and improvements can be made without departing from the concepts herein. Except where mutually exclusive, any of the features may be employed separately or in combination with any other features and the disclosure extends to and includes all combinations and sub-combinations of one or more features described herein.

Claims

1. A core (400) for an investment casting process in which a component to be cast has an internal passageway, the internal passageway being provided by the core (400), the core (400) comprising: a first core passage (401) having a first point (405) and a second point (406) therein and including no straight path between the first point (405) and the second point (406); and a first core bridge (421a) which extends away from the first core passage (401) between the first and second points (405, 406), wherein the first core bridge (421a) comprises a first pillar (422) and a second pillar (412a) which connect to the first and second points (405, 406) respectively, and a bridge portion (423a) which extends between the first and second pillars (422, 412a); wherein the first pillar (422) comprises a core inlet portion (408) having a thickness at the first point (405) and the second pillar (412a) has a thickness at the second point (406), the thickness of the core inlet portion (408) at the first point (405) being less than the thickness of the second pillar (412a) at the second point (406).

2. A core (400) according to claim 1, wherein the core inlet portion (408) has a height H1 at the first point (405) and the second pillar (412a) has a height H2 at the second point (406), H1 being less than H2.

3. A core (400) according to claim 1 or claim 2, wherein the first core bridge (421a) comprises a transition region (410a) between the core inlet portion (408) and the second pillar (412a).

4. A core according to claim 3, wherein the transition region (410a) is part of the first pillar (422), the bridge portion (423a) and/or the second pillar (421a).

5. A core (400) according to claim 3 or claim 4 when dependent on claim 2, wherein the transition region (410a) comprises a sloping upper surface (411a), which connects an upper surface (409) of the core inlet portion (408) to an upper surface (414a) of the second pillar (412a).

6. A core (400) according to any one of claims 3 to 5, wherein the transition region (410a) comprises one or more transition region side walls (413a, 413a') connecting one of the side walls of the core inlet portion (408) to one of the side walls of the second pillar (412a).

7. A core (400) according to any one of the preceding claims, wherein the core inlet portion (408) comprises at least one indent, groove or recess extending in a transverse direction at least partially across a side wall of the core inlet portion (408).

8. A core (400) according to any one of the preceding claims comprising one or more shell lock features (415a, 415b).

9. A core (400) according to any one of the preceding claims comprising more than one core bridge (421a, 421b).

10. A core (400) according to claim 9, wherein the core inlet portion (408) is common to more than one core bridge (421a, 421b).

11. A ceramic shell for an investment casting process in which a component to be cast has at least one internal passageway, the internal passageway(s) being provided by a core, the ceramic shell comprising: a core (400) according to any one of claims 1 to 10, the core having an outer layer of a sacrificial material within the ceramic shell, wherein the first core bridge (421a) extends between the first core passage (404) and the ceramic shell through the sacrificial material.

12. A cast component (700) comprising: at least one internal passageway formed by a core (400) of any one of claims 1 to 10, the cast component (700) having an aperture (702) to the internal passageway at a first point and a cap sealing an aperture at a second point, wherein the apertures at the first and second points respectively correspond to the connections of the core inlet portion (408) and second pillar (412a) provided by the core (400).

13. A cast component (700) according to claim 12, wherein the cast component (700) is a seal segment for bounding a portion of a main gas path of a gas turbine engine or the cast component (700) is a combustion tile.

14. A cast component (700) according to claim 12 or claim 13, wherein the at least one internal passageway has a local area contraction corresponding to an indent, groove or recess on the core (400).

15. A gas turbine engine (10) comprising a cast component (700) of any one of claims 12 to 14.

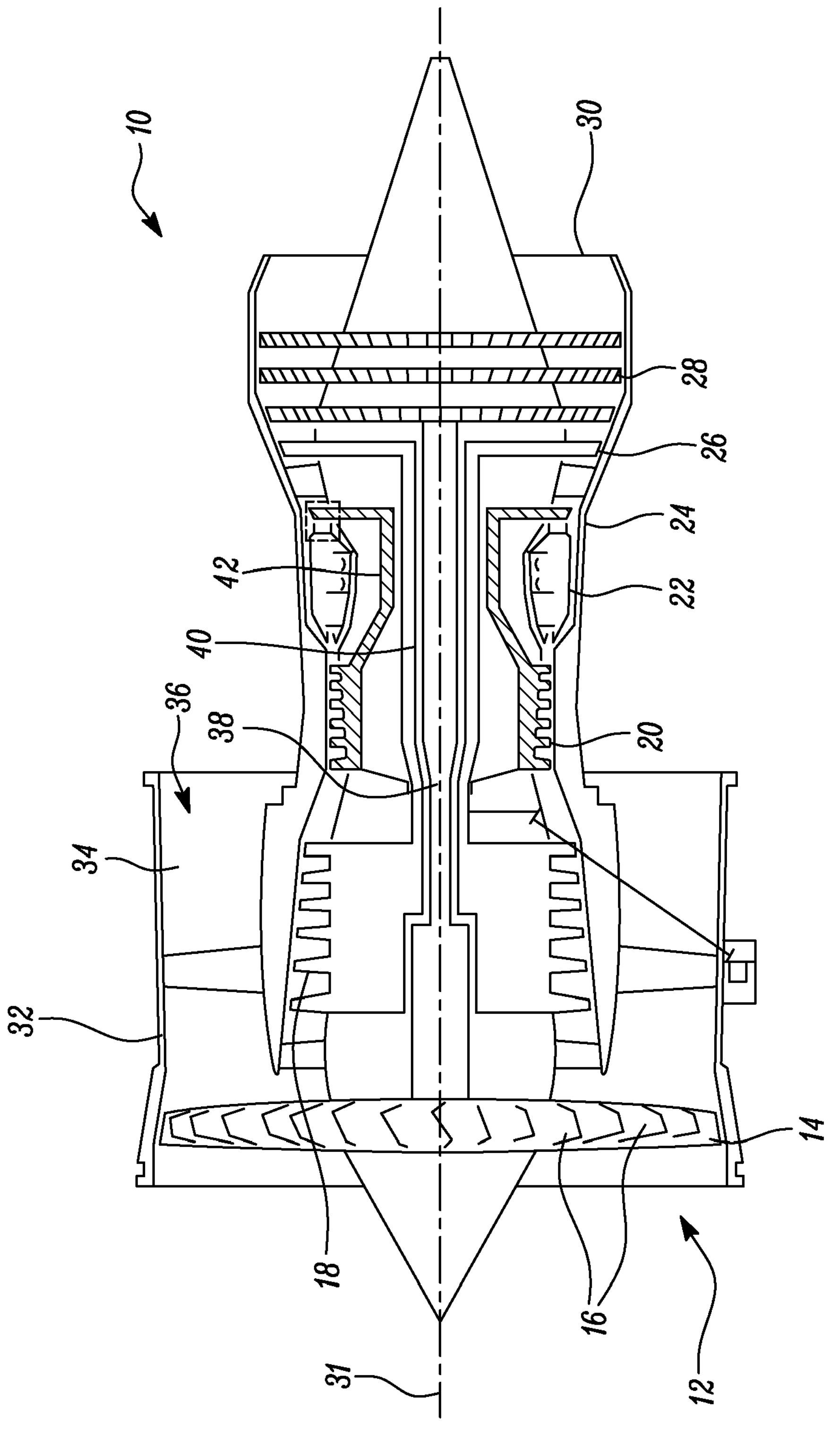


FIG. 1

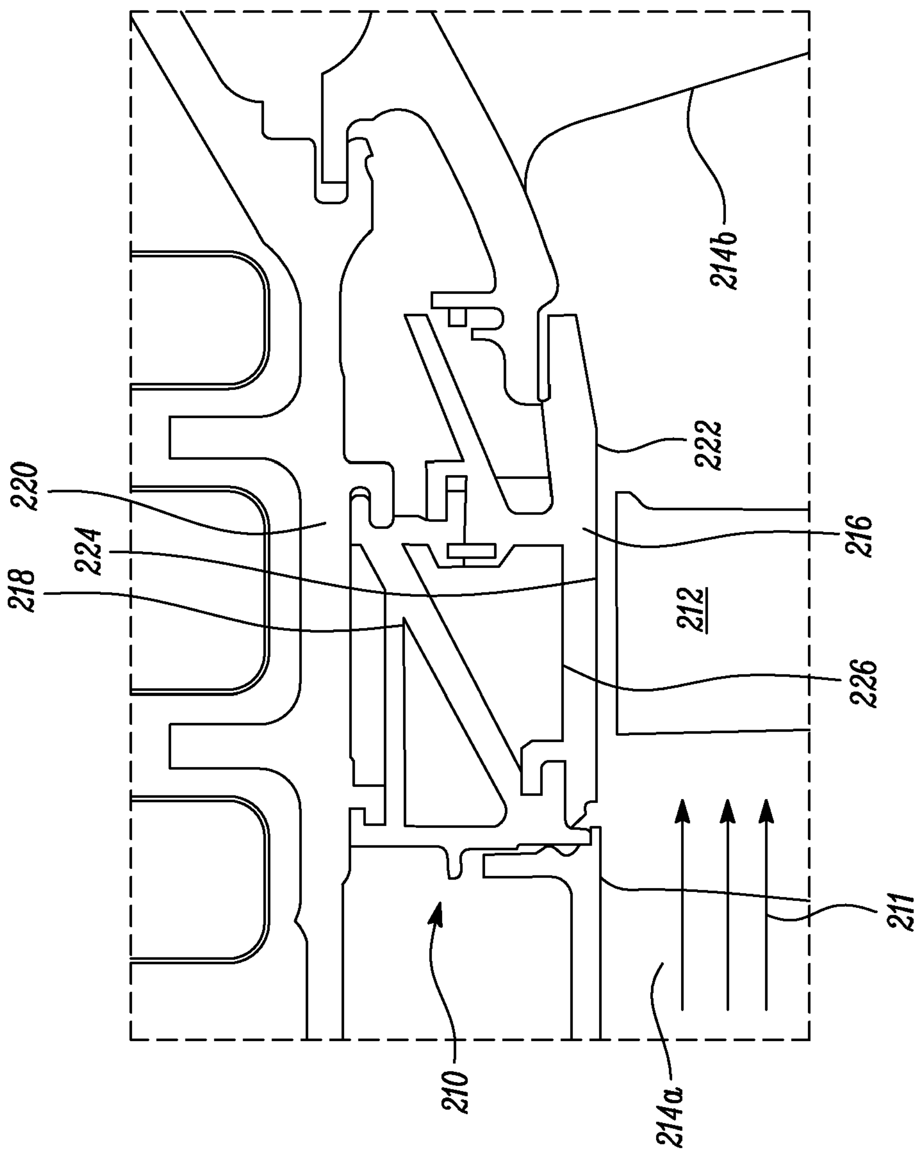


FIG. 2

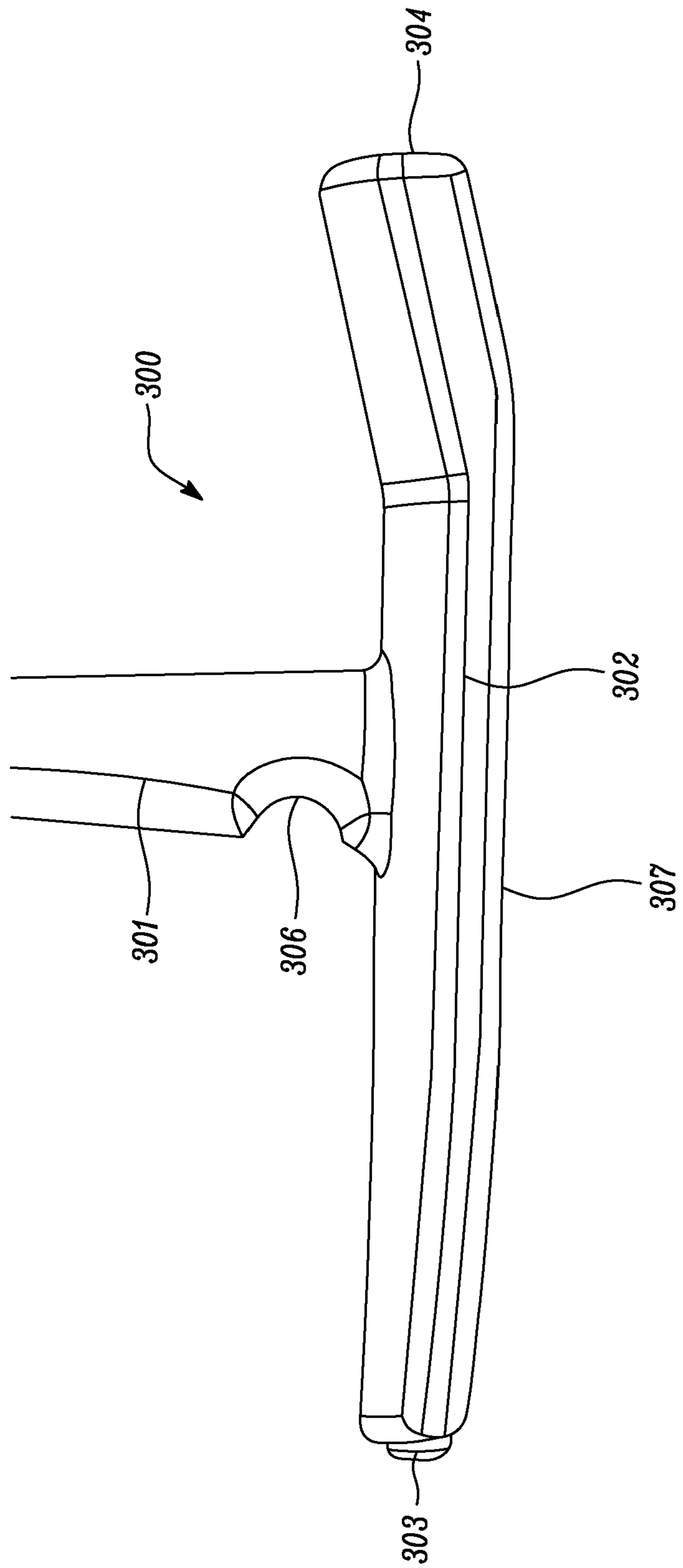
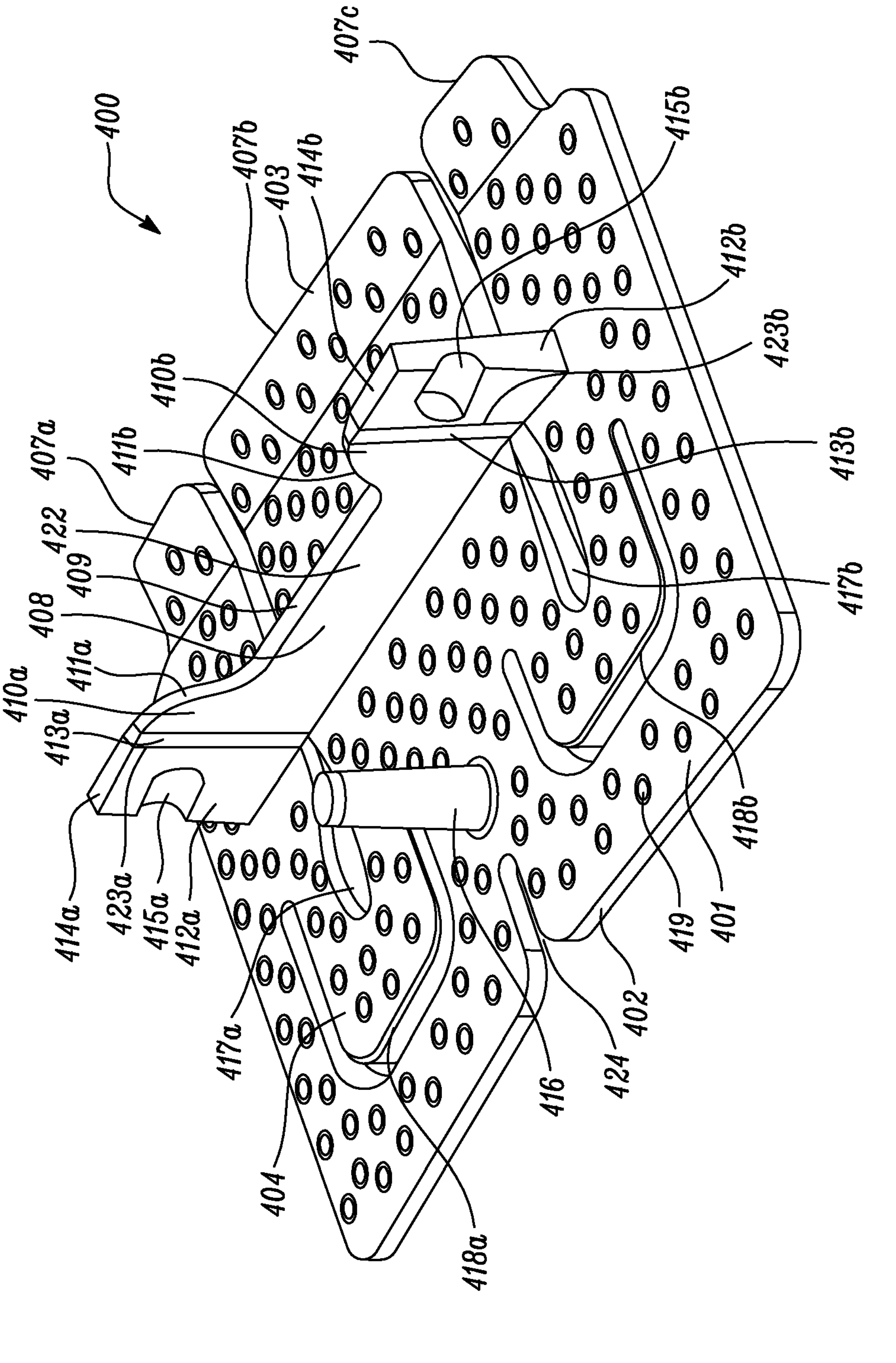


FIG. 3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403
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415b
412b
423b
410b
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411b
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413a
413b
417b
418b
401
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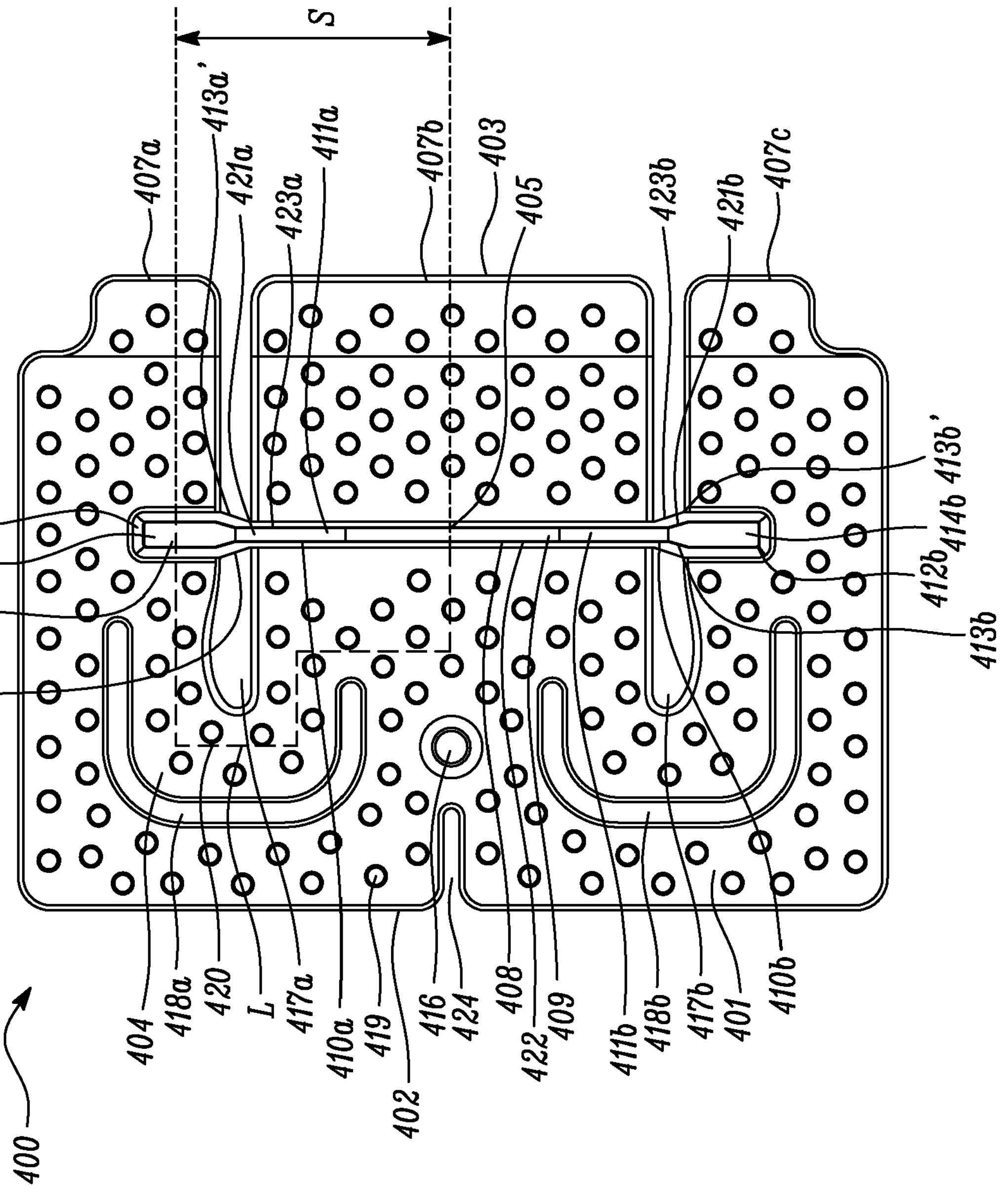
404
417a
412a
415a
423a
414a

FIG. 4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411b
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410b
413a
406
414a
412a
407a
413a'
421a
423a
411a
407b
403
405
423b
421b
407c
413b'
414b
412b
413b
S

FIG. 5

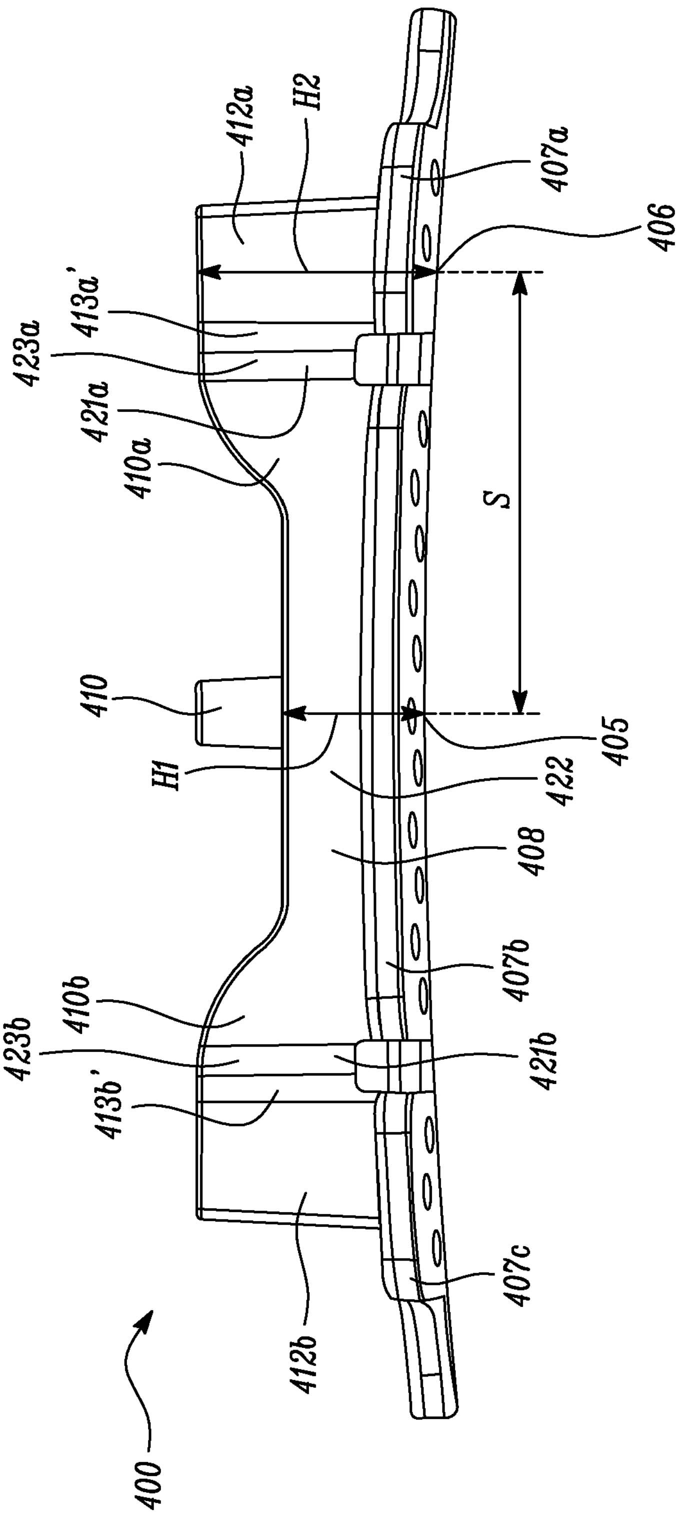
412a
H2
407a
406
413a'
423a
421a
410a
S
410
405
H1
422
408
407b
410b
423b
421b
413b'
407c
412b
400

FIG. 6

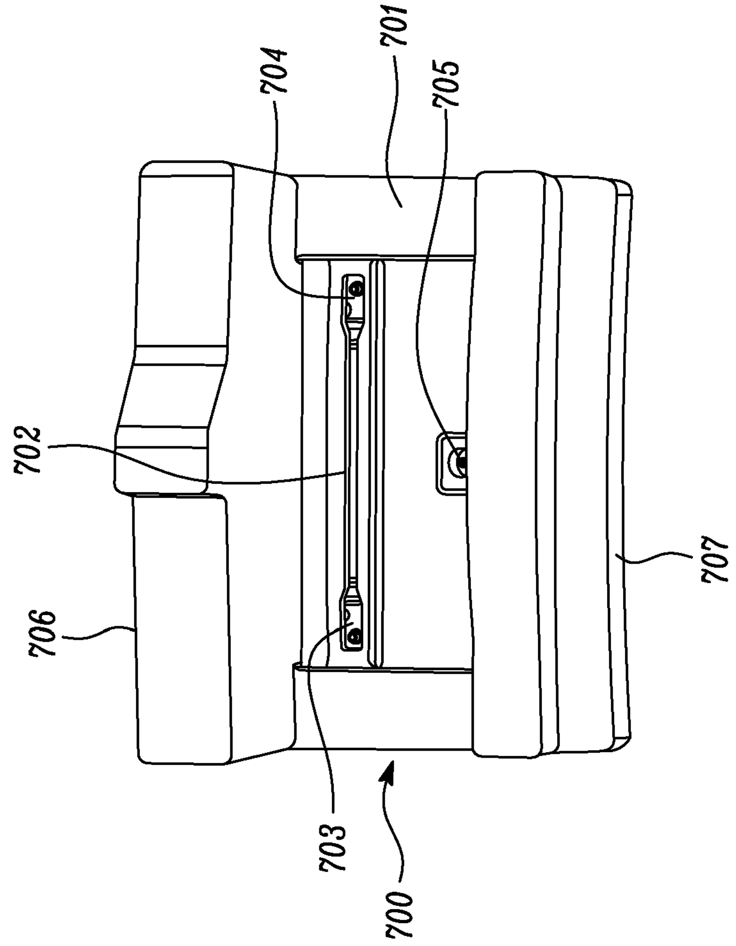

FIG. 7

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EUROPEAN SEARCH REPORT

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EP 19 15 5458

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	19 June 2019	Desvignes, Rémi

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EUROPEAN SEARCH REPORT

Application Number
EP 19 15 5458

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