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(54) Titre : COULAGE DE PREMIERES COMPOSANTES METALLIQUES ET DE DEUXIEMES COMPOSANTES METALLIQUES

(54) Title: CASTING WITH FIRST METAL COMPONENTS AND SECOND METAL COMPONENTS

(57) **Abrégé/Abstract:**

The present disclosure generally relates to casting molds including a casting core comprising a first metal component and a second metal component. In an aspect, the first metal component has a lower melting point than the second metal component. In another aspect, the second metal component surrounds at least a portion of the first metal component and defines a cavity in the casting core when the first metal component is removed and the second metal component is not removed.



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ABSTRACT

The present disclosure generally relates to casting molds including a casting core comprising a first metal component and a second metal component. In an aspect, the first metal component has a lower melting point than the second metal component. In another aspect, the second metal component surrounds at least a portion of the first metal component and defines a cavity in the casting core when the first metal component is removed and the second metal component is not removed.

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## CASTING WITH FIRST METAL COMPONENTS AND SECOND METAL COMPONENTS

### INTRODUCTION

[0001] The present disclosure generally relates to casting core components and processes utilizing these core components. The core components of the present invention may include one or more first metal components and one or more second metal components. The first metal component(s) and the second metal component(s) provide useful properties in casting operations, such as in the casting of superalloys used to make turbine blades for jet aircraft engines or power generation turbine components.

### BACKGROUND

[0002] Many modern engines and next generation turbine engines require components and parts having intricate and complex geometries, which require new types of materials and manufacturing techniques. Conventional techniques for manufacturing engine parts and components involve the laborious process of investment or lost-wax casting. One example of investment casting involves the manufacture of a typical rotor blade used in a gas turbine engine. A turbine blade typically includes hollow airfoils that have radial channels extending along the span of a blade having at least one or more inlets for receiving pressurized cooling air during operation in the engine. Among the various cooling passages in the blades, includes serpentine channel disposed in the middle of the airfoil between the leading and trailing edges. The airfoil typically includes inlets extending through the blade for receiving pressurized cooling air, which include local features such as short turbulator ribs or pins for increasing the heat transfer between the heated sidewalls of the airfoil and the internal cooling air.

[0003] The manufacture of these turbine blades, typically from high strength, superalloy metal materials, involves numerous steps. First, a precision ceramic core is manufactured to conform to the intricate cooling passages desired inside the turbine blade. A precision

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die or mold is also created which defines the precise 3-D external surface of the turbine blade including its airfoil, platform, and integral dovetail. The ceramic core is assembled inside two die halves which form a space or void therebetween that defines the resulting metal portions of the blade. Wax is injected into the assembled dies to fill the void and surround the ceramic core encapsulated therein. The two die halves are split apart and removed from the molded wax. The molded wax has the precise configuration of the desired blade and is then coated with a ceramic material to form a surrounding ceramic shell. Then, the wax is melted and removed from the shell leaving a corresponding void or space between the ceramic shell and the internal ceramic core. Molten superalloy metal is then poured into the shell to fill the void therein and again encapsulate the ceramic core contained in the shell. The molten metal is cooled and solidifies, and then the external shell and internal core are suitably removed leaving behind the desired metallic turbine blade in which the internal cooling passages are found.

[0004] The cast turbine blade may then undergo additional post casting modifications, such as but not limited to drilling of suitable rows of film cooling holes through the sidewalls of the airfoil as desired for providing outlets for the internally channeled cooling air which then forms a protective cooling air film or blanket over the external surface of the airfoil during operation in the gas turbine engine. However, these post casting modifications are limited and given the ever increasing complexity of turbine engines and the recognized efficiencies of certain cooling circuits inside turbine blades, the requirements for more complicated and intricate internal geometries is required. While investment casting is capable of manufacturing these parts, positional precision and intricate internal geometries become more complex to manufacture using these conventional manufacturing processes. Accordingly, it is desired to provide an improved casting method for three dimensional components having intricate internal voids.

[0005] Precision metal casting using hybrid core components utilizing a combination of refractory metal and ceramic casting components is known in the art. Hybrid cores have been made that include portions of refractory metal and ceramic material. For example, See U.S. 2013/0266816 entitled "Additive manufacturing of hybrid core." The

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techniques used to manufacture hybrid cores disclosed in this application utilized conventional powder bed technology. Although hybrid cores offer additional flexibility for casting of superalloys for example in the casting of turbine blades used in jet aircraft engines, there remains a need for more advanced investment casting core technology.

## SUMMARY

[0006] The present disclosure generally relates to casting molds including a casting core comprising a first metal component and a second metal component. In an aspect, the first metal component may have a lower melting point than the second metal component. In another aspect, the second metal component may surround at least a portion of the first metal component and define a cavity in the casting core when the first metal component is removed. One or more of the first metal component and/or the second metal component may be formed by additive manufacturing processes using advanced methods of direct laser melting and/or sintering described herein. The casting core may further include an outer shell mold formed from a ceramic material.

[0007] In an example embodiment, the first metal component may include aluminum, copper, silver, and/or gold and the second metal component may include molybdenum, niobium, tantalum, and/or tungsten. In addition, the first metal component and/or the second metal component may include an alloy.

[0008] One or more of the first metal component and/or the second metal component may be adapted to define within a cast component cooling holes, trailing edge cooling channels, or micro channels among other structures. The first metal component and/or the second metal component may also be adapted to provide a core support structure, a platform core structure, or a tip flag structure. Several metal components of non-refractory metal and/or refractory metal may be used in a single casting core, or may be used either alone or with other casting components in a ceramic casting core assembly.

[0009] The present invention also relates to methods of making a cast component comprising removing a first metal component from a casting mold assembly comprising a

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first metal component and a second metal component to create a cavity within the mold assembly, the first metal component having a lower melting point than the second metal component, pouring a molten metal into at least a portion of the cavity to form the cast component, and removing the second metal component from the cast component.

[0010] In another aspect, the entire casting core including the first metal component and the second metal component may be made by a direct laser melting/sintering from a powder bed. Alternatively, the first metal component and the second metal component may be assembled within a mold and a ceramic slurry may be introduced to create the casting core.

[0011] In another aspect, the first metal component and second metal component may be formed together using an AM process. In one embodiment of a possible AM process the first metal component and second metal component may be built on a layer-by-layer basis by a process including the steps of (a) consolidating through irradiation binder injection, and/or sintering a layer of powder in a powder bed to form a fused/sintered region; (b) providing a subsequent layer of powder over the powder bed; and (c) repeating steps (a) and (b) using at least two different powder compositions corresponding to at least the first metal component and the second metal component.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 is a schematic diagram showing an example of a conventional apparatus for additive manufacturing.

[0013] FIG. 2 is a perspective view of an additive manufacturing device that allows for production of parts having differing compositions throughout the build.

[0014] FIG. 3 is a top view of a component being manufactured using the additive manufacturing device shown in FIG. 2.

[0015] FIG. 4 shows a method of forming a cast component in accordance with an embodiment of the present invention.

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[0016] FIG. 5 shows a method of forming a cast component in accordance with an embodiment of the present invention.

[0017] FIG. 6 shows a method of forming a cast component in accordance with an embodiment of the present invention.

[0018] FIG. 7 shows a method of forming a cast component in accordance with an embodiment of the present invention.

[0019] FIG. 8 shows a method of forming a cast component in accordance with an embodiment of the present invention.

#### DETAILED DESCRIPTION

[0020] The detailed description set forth below in connection with the appended drawings is intended as a description of various configurations and is not intended to represent the only configurations in which the concepts described herein may be practiced. The detailed description includes specific details for the purpose of providing a thorough understanding of various concepts. However, it will be apparent to those skilled in the art that these concepts may be practiced without these specific details.

[0021] The first metal component and/or the second metal component of the present invention may be made using an additive manufacturing (AM) process. AM processes generally involve the buildup of one or more materials to make a net or near net shape (NNS) object, in contrast to subtractive manufacturing methods. Though "additive manufacturing" is an industry standard term (ASTM F2792), AM encompasses various manufacturing and prototyping techniques known under a variety of names, including freeform fabrication, 3D printing, rapid prototyping/tooling, etc. AM techniques are capable of fabricating complex components from a wide variety of materials. Generally, a freestanding object can be fabricated from a computer aided design (CAD) model. A particular type of AM process uses an energy beam, for example, an electron beam or electromagnetic radiation such as a laser beam, to sinter or melt a powder material,

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creating a solid three-dimensional object in which particles of the powder material are bonded together. Different material systems, for example, engineering plastics, thermoplastic elastomers, metals, and ceramics are in use. Laser sintering or melting is a notable AM process for rapid fabrication of functional prototypes and tools. Applications include direct manufacturing of complex workpieces, patterns for investment casting, metal molds for injection molding and die casting, and molds and cores for sand casting. Fabrication of prototype objects to enhance communication and testing of concepts during the design cycle are other common usages of AM processes.

[0022] Selective laser sintering, direct laser sintering, selective laser melting, and direct laser melting are common industry terms used to refer to producing three-dimensional (3D) objects by using a laser beam to sinter or melt a fine powder. For example, U.S. Patent Number 4,863,538 and U.S. Patent Number 5,460,758 describe conventional laser sintering techniques. More accurately, sintering entails fusing (agglomerating) particles of a powder at a temperature below the melting point of the powder material, whereas melting entails fully melting particles of a powder to form a solid homogeneous mass. The physical processes associated with laser sintering or laser melting include heat transfer to a powder material and then either sintering or melting the powder material. Although the laser sintering and melting processes can be applied to a broad range of powder materials, the scientific and technical aspects of the production route, for example, sintering or melting rate and the effects of processing parameters on the microstructural evolution during the layer manufacturing process have not been well understood. This method of fabrication is accompanied by multiple modes of heat, mass and momentum transfer, and chemical reactions that make the process very complex.

[0023] FIG. 1 is schematic diagram showing a cross-sectional view of an exemplary conventional system 100 for direct metal laser sintering (DMLS) or direct metal laser melting (DMLM). The apparatus 100 builds objects, for example, the part 122, in a layer-by-layer manner by sintering or melting a powder material (not shown) using an energy beam 136 generated by a source such as a laser 120. The powder to be melted by the energy beam is supplied by reservoir 126 and spread evenly over a build plate 114

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using a recoater arm 116 travelling in direction 134 to maintain the powder at a level 118 and remove excess powder material extending above the powder level 118 to waste container 128. The energy beam 136 sinters or melts a cross sectional layer of the object being built under control of the galvo scanner 132. The build plate 114 is lowered and another layer of powder is spread over the build plate and object being built, followed by successive melting/sintering of the powder by the laser 120. The process is repeated until the part 122 is completely built up from the melted/sintered powder material. The laser 120 may be controlled by a computer system including a processor and a memory. The computer system may determine a scan pattern for each layer and control laser 120 to irradiate the powder material according to the scan pattern. After fabrication of the part 122 is complete, various post-processing procedures may be applied to the part 122. Post processing procedures include removal of excess powder by, for example, blowing or vacuuming. Other post processing procedures include a stress relief process.

[0024] The traditional laser melting/sintering techniques described above have certain limitations in regard to producing AM objects having varying compositions. For example, although it is possible to vary the composition of the powder in successive layers this can become cumbersome particularly in an industrialized setting where downtime between manufacturing steps comes at a high cost. Recently, more advanced methods of laser melting/sintering have been developed that allow precise control of the composition of the build both between successive powder layers of the build but laterally within the same powder layer. *See* CA Patent Application No. 2,939,745 filed August 19, 2016, and entitled “Coater Apparatus and Method for Additive Manufacturing.”

[0025] As shown in FIG. 2, the advanced powder bed machine includes a reservoir assembly 30 positioned above a dispenser 32. The dispenser 32 includes one or more elongated troughs 38A-E. The elongated troughs include a deposition valve (binary or variable) between the trough and the build plate that control the deposition of powder on the build plate 12.

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[0026] The reservoir assembly 30 includes at least one reservoir disposed over each trough 38A-E. As shown in Fig. 2, the reservoir assembly includes for example 20 reservoirs. Each reservoir is defined by suitable walls or dividers forming a volume effective to store and dispense a powder, referred to generally at "P" (i.e., P1, P2, P3, etc.). Each individual reservoir may be loaded with a powder P having unique characteristics, such as composition and/or powder particle size. For example, P1 may be used to build part 60, P2 may be used to build part 62, and P3 may be used to build part 64. It should be appreciated that the powder P may be of any suitable material for additive manufacturing. For example, the powder P may be a metallic, polymeric, organic, or ceramic powder. It is noted that the reservoir assembly 30 is optional and that powder P may be loaded directly into the troughs 38.

[0027] Optionally, it may be desired to purge the troughs 38A-E between cycles of the process, for example where it is desired to deposit different mixtures of powder from previous cycles. This may be accomplished by moving the trough 38A-E over the excess powder container 14 and then opening the deposition valves to dump the excess powder. The process may be augmented by flowing a gas or mixture of gases through the troughs 38A-E.

[0028] FIG. 3 shows one-half of a powder layer for the component C which has been subdivided into a grid that is 10 elements wide by 15 elements tall. The size of the grid elements and their spacing are exaggerated for purposes of clarity in illustration. The representation of the component C as a series of layers each with a grid of elements may be modeled, for example, using appropriate solid modeling or computer-aided design software. Each unique hatching pattern shown in FIG. 4 represents the characteristics of one unique powder (e.g. composition and/or particle size). As shown, a single layer of powder may include different types of powder (e.g., P1, P2, and P3). Although three different types of powder are illustrated in FIG. 3, it should be understood that more or fewer types of powder may be used without departing from the scope of the present disclosure.

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[0029] This cycle of applying powder P and then laser melting the powder P is repeated until the entire component C is complete.

[0030] Other techniques may be employed to provide a core component according to the invention. For example, the component may be made using an injection molding technique that utilizes different materials within the same core component.

[0031] The core component of the present disclosure may be used to provide a cooling feature in the final product such as cooling holes, trailing edge cooling channels, micro channels, crossover holes that connect two cooling cavities, internal impingement holes in double walled or near-wall cooling structures, refresher holes in the root turns of blades, as well as additional cooling features known in the art. In addition, the core component may be used to match the thermal expansion characteristics of two or more materials. The core component of the present disclosure may also be used to add or dope certain regions of a cast metal object with a desired element or alloy.

[0032] The additive manufacturing techniques described above enable formation of almost any desired shape and composition of a core component. The core component of the present disclosure may optionally be assembled with other metal pieces and/or ceramic components. In one embodiment, the core component and any other optional components may be utilized within a core portion of a ceramic mold, such as used in the manufacture of superalloy turbine blades for jet aircraft engines. A mold may then be prepared and molten superalloy poured into the cavity of the mold including contact with a metal component. The mold component may be removed from the mold using a combination mechanical and chemical process. The ceramic material may be leached out using a caustic solution under elevated temperature and/or pressure. The graded core component(s) may then be chemically etched away from the formed superalloy component using an acid treatment. In one aspect, the graded core component is sintered rather than melted. This may increase the number of options for removing the graded core component. For example, in some cases the sintered (incompletely fused) metal may be removed using physical means (e.g., shaking). In addition, sintered material may be more

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readily removed using an acid etch where the etch solution more rapidly penetrates the sintered powder structure.

[0033] FIGs. 4-8 illustrate a method of making a cast component 414 using a casting mold 400 in accordance with certain aspects of the present disclosure. For example, referring to FIG. 4, the casting mold may include a first metal component 402 and a second metal component 404. Optionally, the casting mold 400 may also include an outer shell mold (not shown) that surrounds at least a portion of the first metal component 402 and the second metal component 404. In one aspect, the casting mold 400 may be used to cast a jet aircraft component such as a single-crystal superalloy turbine blade.

[0034] Still referring to FIG. 4, the first metal component 402 and the second metal component 404 may be formed using the additive manufacturing techniques described *supra* with respect to FIGs. 1-3. For example, the first metal portion 402 and the second metal component 404 may be formed simultaneously using additive manufacturing. Alternatively, the first metal component 402 and the second metal component 404 may be formed separately. In one aspect, the first metal component 402 and the second metal component 404 may be formed using the same manufacturing technique (e.g., additive manufacturing). Additionally and/or alternatively, the first metal component 402 and the second metal component 404 may be formed using different manufacturing techniques.

[0035] If an outer shell mold (not illustrated) is included, it may be formed around the first metal component 402 and the second metal component 404. Alternatively, the first metal component 402 and the second metal component 404 may be placed within the outer shell mold.

[0036] The first metal component 402 may include a metal with a lower melting point than the second metal component 404. In an example embodiment, the first metal component may include a low melting point metal and/or alloy including, but not limited to, at least one of aluminum, nickel, cobalt, chrome, copper, gold, and/or silver or combinations or alloys thereof. In another example embodiment, the second metal component 404 may include a refractory metal and/or refractory metal alloy including,

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but not limited to, at least one of molybdenum, niobium, tantalum and/or tungsten or combinations or alloys thereof. These example embodiments are not intended to be limiting. For example, the first metal component 402 may include any metal that has a lower melting point than the metal used for the second metal component 404. Similarly, the second metal component 404 may include any metal that has a higher melting point than the metal used for the first metal component 402.

[0037] In one aspect, the metals of the first metal component 402 and/or the second metal component 404 may be optionally chosen to locally alter the composition of the cast component 414 by diffusing one or more elements or alloys into the superalloy component.

[0038] The shape of the second metal component 404 illustrates how core components may be used to form small diameter cooling holes 416a, 416b (illustrated in FIG. 8) and non-linear, non-line of sight cooling holes (not shown) within the wall of a turbine blade 414. The first metal component 402 and/or the second metal component 404 may be used to form cooling holes, trailing edge cooling channels, or micro channels in a cast component. In addition, the first metal component 402 and/or the second metal component 404 may be used for a core support structure, a platform core structure, or a tip flag structure.

[0039] The refractory metals molybdenum, niobium, tantalum, and tungsten may be used in accordance with the present disclosure and are commercially available in forms already used for hybrid core components. Some refractory metals may oxidize or dissolve in molten superalloys. Refractory metal core components may be coated with ceramic layers for protection. Alternatively, the second metal component 404 may include a graded transition to a surface having a ceramic layer that is 0.1 to 1 mil thick for protection. The protective ceramic layer may include silica, alumina, zirconia, chromia, mullite and hafnia.

[0040] The first metal component 402 and/or the second metal component 404 may have a graded transition to a layer of another metal such as a noble metal (i.e., platinum) or

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chromium or aluminum to protect against oxidation. These metal layers may be applied alone or in combination with the ceramic layer discussed *supra*.

[0041] In addition, the second metal component 404 may include a material that forms a surface protective film upon heating may be used. For example,  $\text{MoSi}_2$ , respectively forms a protective layer of  $\text{SiO}_2$ .

[0042] As illustrated in FIG. 5, the first metal layer 402 may be removed from the casting mold 400 to form a cavity 406 defined at least in part by the second metal component 404. In the example illustrated in FIG. 5, the cavity 406 is formed within the second metal component 404. In one aspect, the first metal component 402 may be removed from the casting mold 400 by melting the first metal component 402. In an example embodiment, the first metal component 402 may be chosen such that its melting point is lower than the melting point of the second metal component 404. In this way, the first metal component 402 may be melted and removed without melting or causing damage to the second metal component 404.

[0043] As illustrated in FIG. 6, a liquid metal 408 may be poured into the cavity 406. The liquid metal 408 may be a liquid superalloy. For example, the liquid metal 408 may include a nickel based alloy including inconel, among others. The liquid metal 408 may be solidified to form a solidified metal 410, as illustrated in FIG. 7.

[0044] After forming the solidified metal 410, the second metal component 404 may be removed to expose the cast component 414, as illustrated in FIG. 8. The removal of the second metal component 404 may be by chemical means (e.g., etching and/or an acid treatment) The second metal component 404 may be removed using a chemical means that does not remove or cause damage to the solidified metal 410. If used as part of the casting mold 400, the outer shell mold (not shown) may be removed by mechanical means such as breaking. The outer shell mold may be removed before or after the second metal component 404.

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[0045] The first metal component 402 and the second metal component 404 may be removed during and/or after forming a superalloy cast component. The first metal component 402 may be chosen such that it has a lower melting point than the second metal component 404. In this way, the first metal component 402 may be melted and removed without melting and/or causing damage to the second metal component 404. Thereafter, the melted superalloy may be poured into a cavity formed by removing the first metal component 402 and by leaving the second metal component 404. The removal of the second metal component 404 may be performed after solidifying the melted superalloy to produce the cast component (e.g., turbine blade). For example, the second metal component 404 may be removed using chemical means including, but not limited to, etching using an acid treatment. The etching to remove the second metal component may be performed before or after immersion in a caustic solution under elevated temperature and pressure to remove any ceramics. In one aspect, the second metal component 402 may be sintered rather than melted. This may increase the number of options for removing the second metal component 402. For example, in some cases the sintered (incompletely fused) second metal may be removed using physical means (e.g., shaking). In addition, sintered material may be more readily removed using an acid etch where the etch solution more rapidly penetrates the sintered powder structure.

[0046] In the above example, the metal that is a first metal component 402 may be used as a disposable pattern material, analogous to wax in the lost wax process for forming a turbine blade. In addition, the first metal component 402 may be used in conjunction with the second metal component 404 within a lost-wax process. In this case, both metal components form a portion of the casting core. The casting core may then be surrounded in wax and, optionally, a ceramic shell. The wax may be removed and in addition, the first metal component 402 may be melted away in the same or different heating step that is used to remove the wax. The first metal component 402 may be used as a gate material in the casting process that provides a passage for subsequently molded material after being melted away.

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[0047] While there have been described herein what are considered to be preferred and exemplary embodiments of the present invention, other modifications of these embodiments falling within the scope of the invention described herein shall be apparent to those skilled in the art.

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## WHAT IS CLAIMED IS:

1. A casting mold comprising:  
a casting core comprising a first metal component and a second metal component,  
wherein the first metal component has a lower melting point than the second metal component, and  
wherein the second metal component surrounds at least a portion of the first metal component and defines a cavity in the casting core when the first metal component is removed.
2. The casting mold of claim 1, wherein the first metal component includes at least one of aluminum, nickel, copper, gold, or silver.
3. The casting mold of claim 1, wherein the first metal component includes an alloy.
4. The casting mold of claim 1, wherein the second metal component includes tungsten or a tungsten alloy.
5. The casting mold of claim 1, wherein the second metal component includes molybdenum or a molybdenum alloy.
6. The casting mold of claim 1, further comprising an outer shell mold surrounding at least a portion of the casting core.
7. The casting mold of claim 6, wherein the outer shell mold includes ceramic.
8. The casting mold of claim 1, wherein the second metal component is configured to define at least one cooling feature in the casting mold.
9. The casting mold of claim 1, wherein the casting core comprises one or more ceramic components.

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10. A method of making a cast component comprising:  
removing a first metal component from a casting mold assembly comprising a first metal component and a second metal component to create a cavity within the mold assembly, the first metal component having a lower melting point than the second metal component;  
pouring a molten metal into at least a portion of the cavity to form the cast component; and  
removing the second metal component from the cast component.
11. The method of claim 10, wherein the first metal component includes at least one of aluminum, nickel, copper, gold, or silver.
12. The method of claim 10, wherein the first metal component includes an alloy.
13. The method of claim 10, wherein the second metal component includes tungsten or a tungsten alloy.
14. The method of claim 10, wherein the second metal component includes molybdenum or a molybdenum alloy.
15. The method of claim 10, wherein the casting mold assembly further includes an outer shell mold that is removed after the molten metal is poured into the at least the portion of the cavity.
16. The method of claim 15, where the outer shell mold comprises ceramic.
17. The method of claim 10, wherein removing the second metal component comprises at least one of etching or an acid treatment.
18. The method of claim 10, wherein the removing the first metal component comprises melting.

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19. The method of claim 10, wherein the method comprises additively forming the first metal component and second metal component on a layer-by-layer basis, comprising steps of:

- (a) irradiating a layer of powder in a powder bed to form a fused region;
- (b) providing a subsequent layer of powder over the powder bed; and
- (c) repeating steps (a) and (b) using at least two different powder compositions corresponding to at least the first metal component and the second metal component.

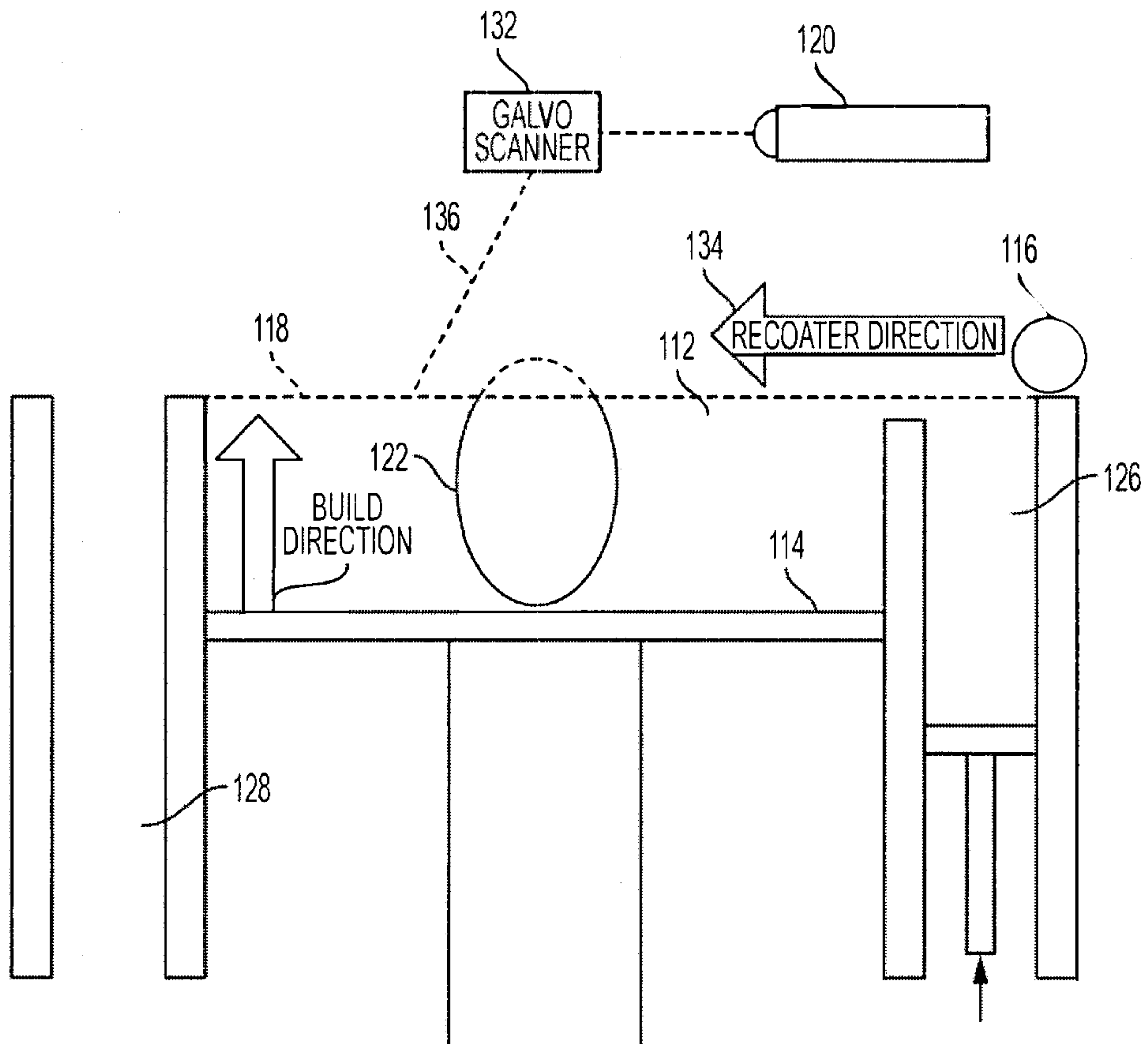


FIG. 1  
PRIOR ART

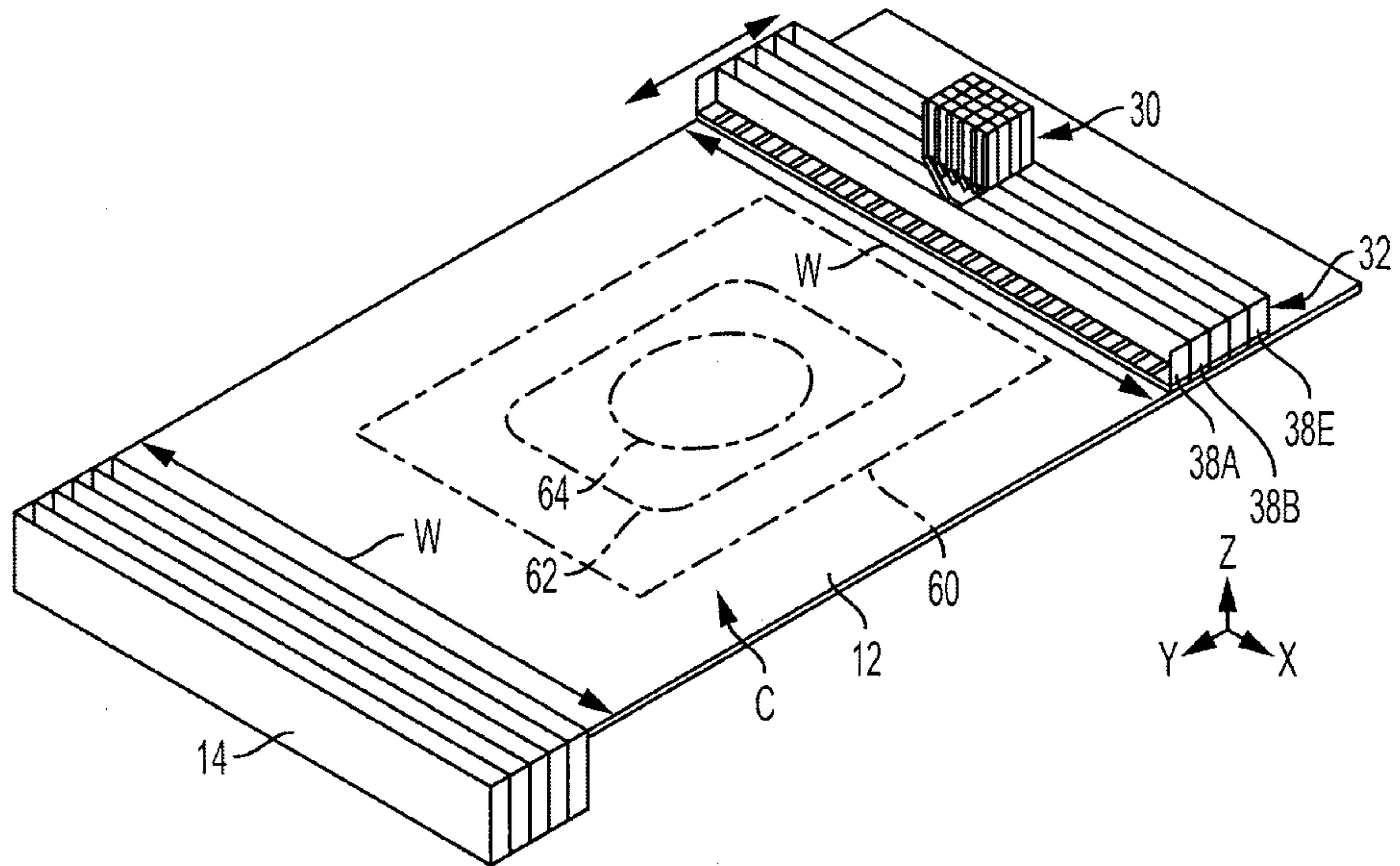


FIG. 2  
PRIOR ART

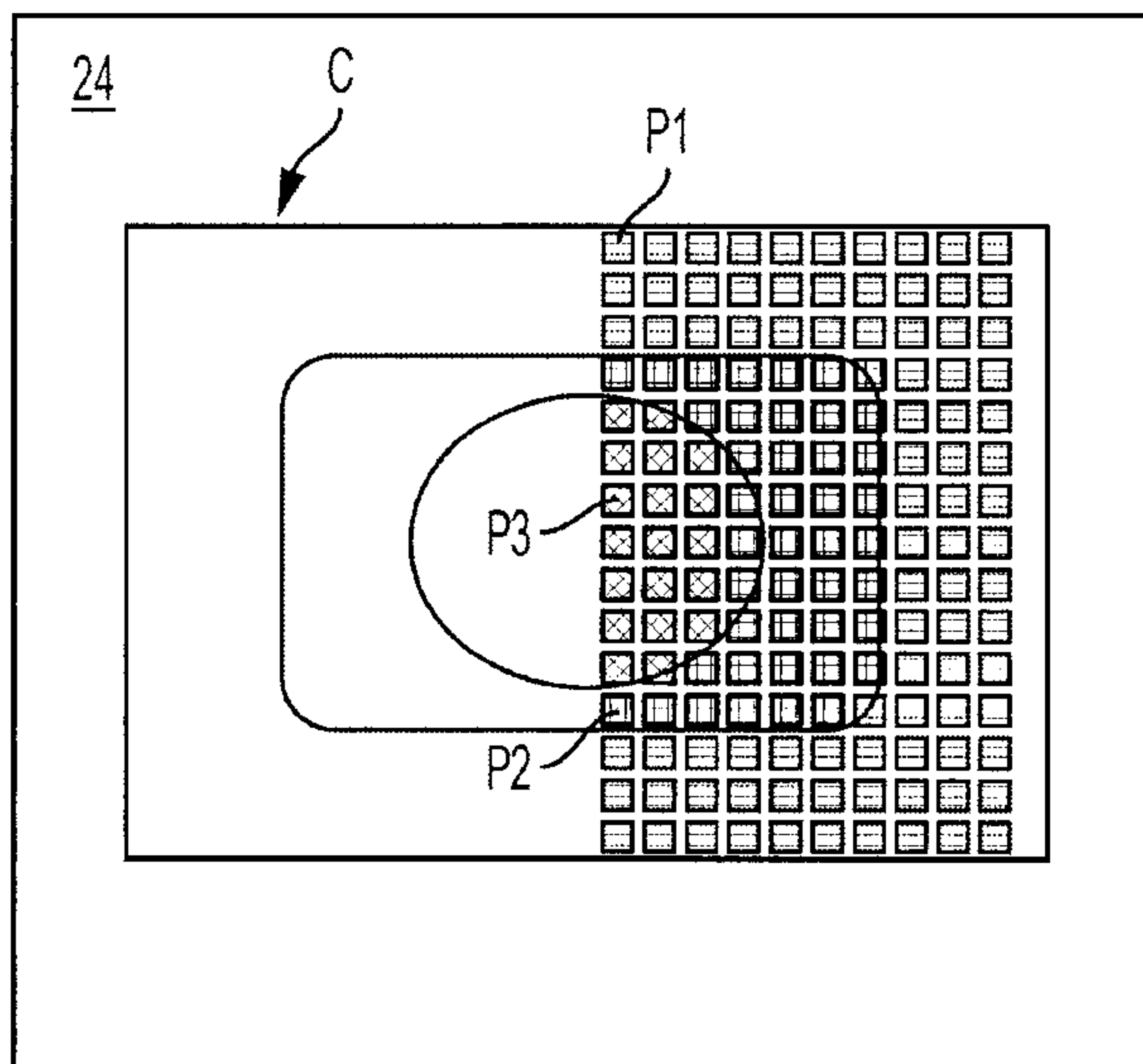


FIG. 3  
PRIOR ART

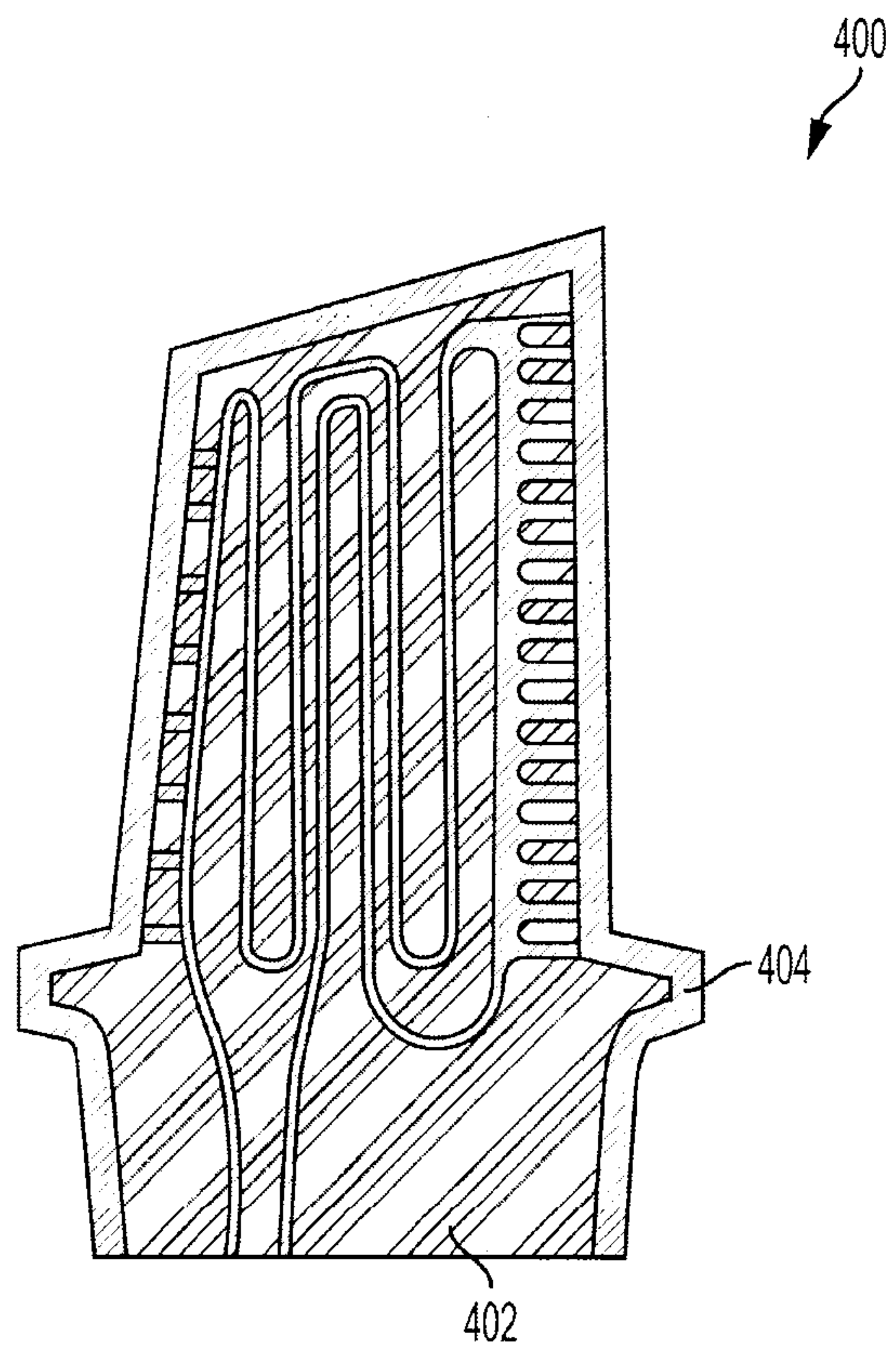


FIG. 4

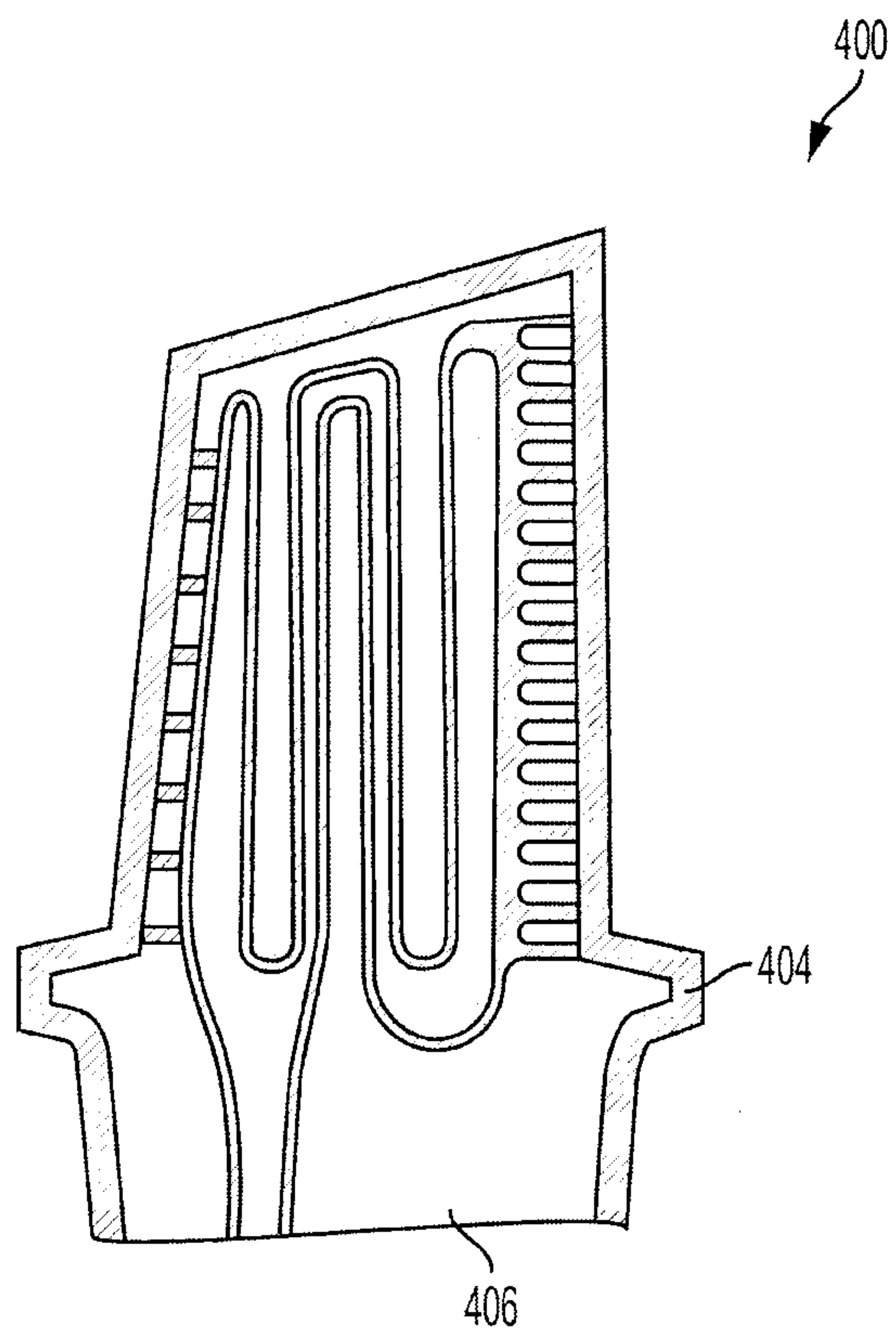


FIG. 5

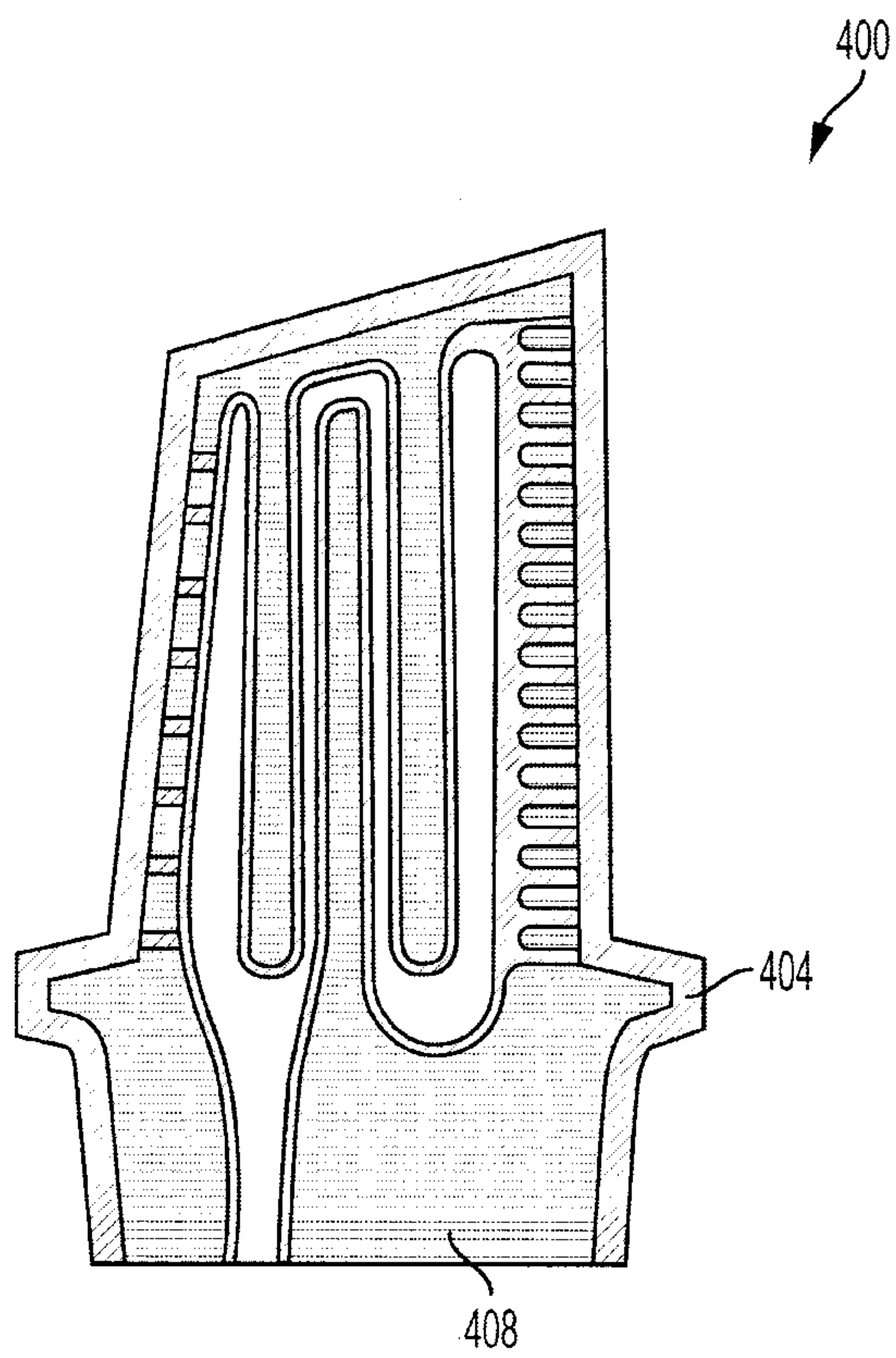


FIG. 6

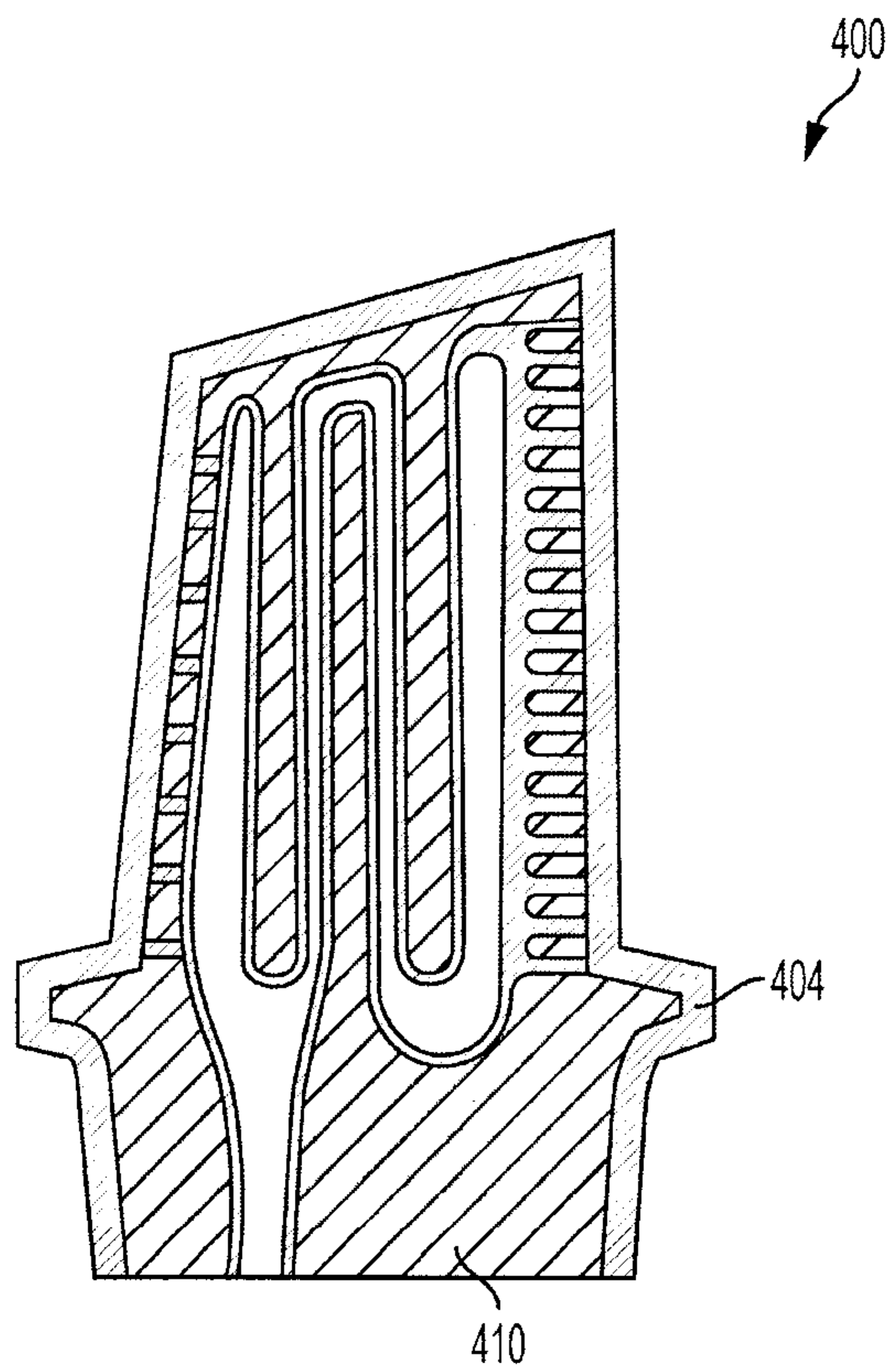


FIG. 7

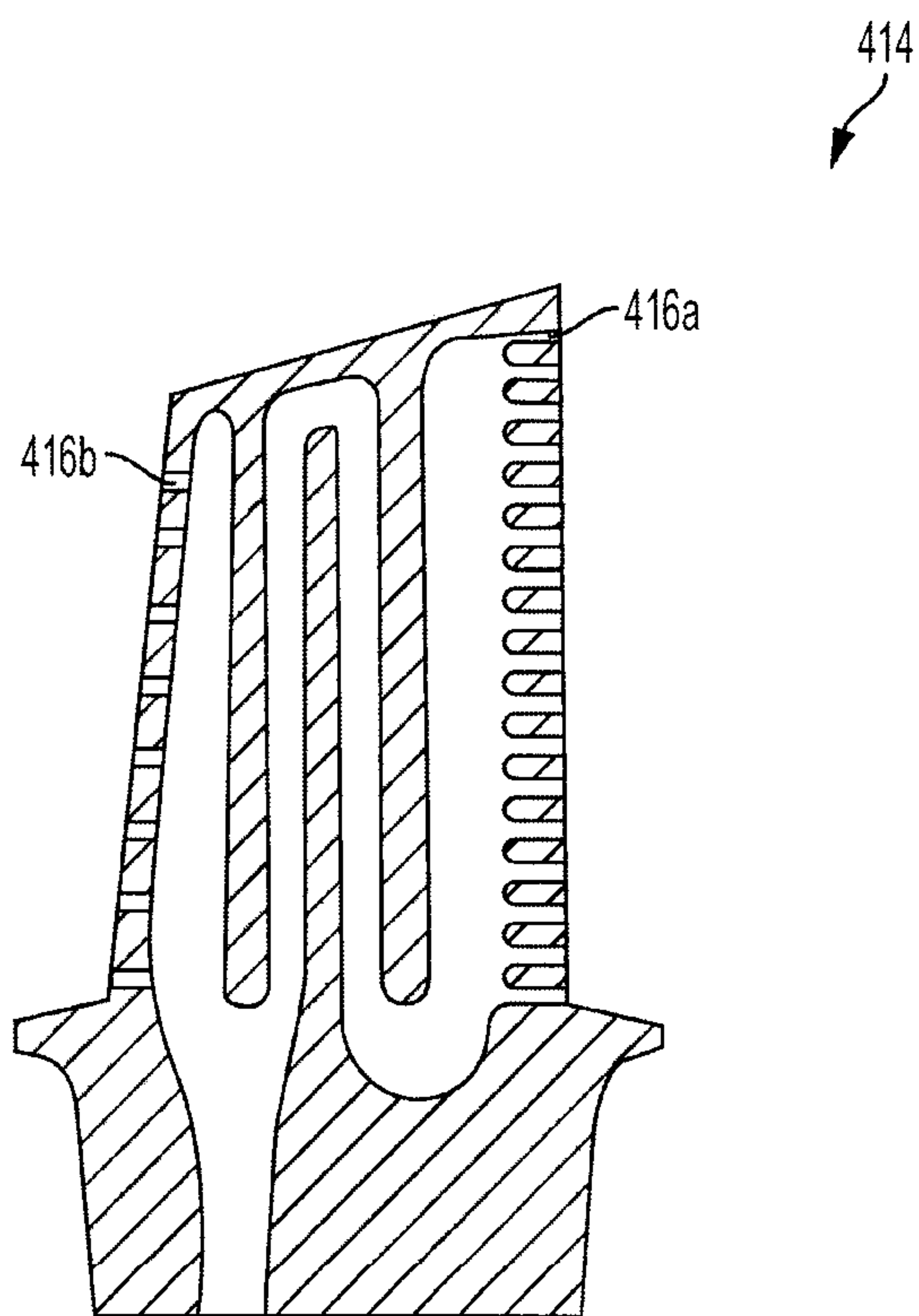


FIG. 8