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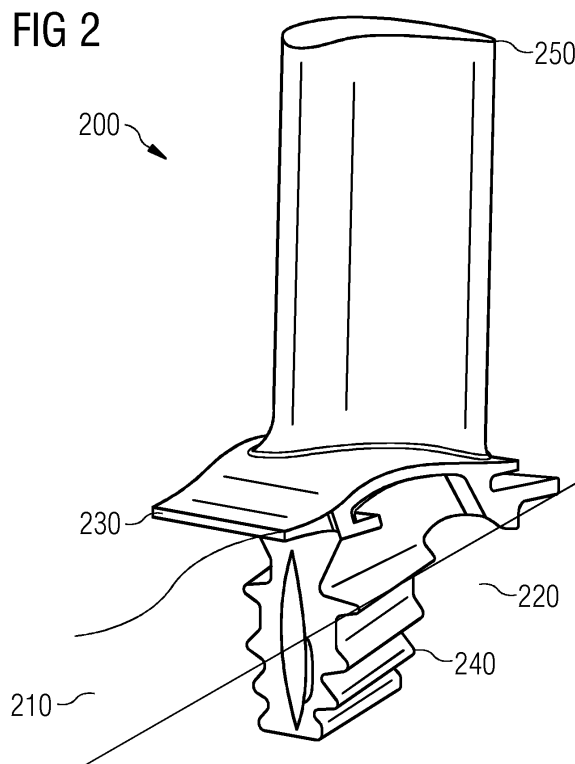
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(54) **IMPROVEMENTS RELATING TO COATINGS FOR METAL ALLOY COMPONENTS**

(57) A coating for a component, such as a turbine aerofoil, which may provide said component with corrosion resistance and which may also provide enhanced resistance to fractures and crack propagation as well as low cycle fatigue resistance, is disclosed. The coating is a platinum aluminide comprising chromium, aluminium, platinum and silicon. The coating is formed of fine grains of the platinum aluminide and coarse grains of the platinum aluminide. The coating may provide an effective

outermost coating on said component. A component comprising such a coating, a method of forming such a coating on a component and a cold spraying apparatus for applying such a coating are also disclosed. Furthermore the relative amounts of fine and coarse grains can be altered in different regions of the coating to provide chemical and/or mechanical properties which are tailored to the requirements in particular regions of a component.



Description

[0001] The present disclosure relates to coatings for components manufactured from metal alloys which may provide improved corrosion resistance and improved mechanical properties to the component compared to known coatings. The present disclosure also relates to components comprising said coatings and to methods of providing said coatings.

[0002] In particular the disclosure is concerned with components, for example turbine aerofoils, having a platinum aluminide coating which comprises coarse grains and fine grains of the platinum aluminide.

Background

[0003] Turbines operate at high temperatures to maximise their fuel efficiency and performance. Operating at high temperatures exposes the components of turbines to hot corrosion processes which can cause catastrophic damage to the turbine components during use. Such damage necessitates costly repairs or replacement of the turbine components. Hot corrosion processes can be classified as Type I (corrosion at 800-950 °C) and Type II (corrosion at 600-800°C). These corrosion processes are caused by salt contaminants such as sodium and potassium salts and V_2O_5 which are drawn into the turbine with the air intake and which then dissolve protective surface oxides due to the low melting point deposits which they normally produce. Some components, for example nickel alloy turbine aerofoils, can experience different temperatures at different regions of the component. It is therefore possible for one region of a component to experience Type I hot corrosion and another region of the component to experience Type II hot corrosion. For example, turbine aerofoils can be exposed to temperatures of 800-900 °C at the aerofoil tip which therefore may suffer Type I hot corrosion, whereas the aerofoil bottom region under the platform may be exposed to temperatures of 600-650 °C and therefore may suffer Type II hot corrosion.

[0004] The use of noble metal containing aluminide coatings on the under-platform surface of the turbine blade may provide corrosion resistance during engine operation. US 6,514,629 B1 discloses an environmentally resistant platinum aluminide coating which is applied through a plasma spray process. US 7,989,020 B2 and US 7,749,569 B2 disclose the use of a silicon modified aluminide coating on the underplatform region for corrosion and oxidation resistance.

[0005] However, such known noble metal coating systems used on the underplatform (bottom) region of turbine aerofoils do not provide the ideal mechanical properties in said region whilst providing this corrosion resistance. For example, it would be desirable for a coating in the bottom region of a turbine aerofoil to have good fracture and crack propagation resistance along with excellent low cycle and hold time fatigue resistance, as well

as improved corrosion resistance. These desirable properties have been known to place conflicting requirements on the design of new coating systems which have not been adequately resolved by the prior art.

[0006] Some known methods for applying coatings to protect components from these corrosion processes involve coating such components using pack aluminide, chemical vapour deposition, high velocity oxy-fuel and electron beam physical vapour deposition. These coating processes involve numerous complicated procedures to finally form the coatings and may result in significant thermal distortion of the component due to the high temperatures employed.

[0007] Also with these known coating processes, it is not possible to coat various regions of a component with different coatings without using sequential coating steps or masking off some regions of the component whilst a different coating is being applied to other regions of the component. These sequential coating steps or masking operations add significantly to the cost of coating such components.

[0008] Hence a coating and coating method which can efficiently provide a component with protection against corrosion whilst providing desirable mechanical properties is highly desirable.

Summary

[0009] According to the present disclosure there is provided a coating, a component comprising a coating, a method of coating a component and an apparatus for coating a component as set forth in the appended claims. Other features of the invention will be apparent from the dependent claims, and the description which follows.

[0010] According to a first aspect of the present invention, there is provided a coating for a component, wherein the coating is a platinum aluminide and wherein the coating comprises fine grains of the platinum aluminide and coarse grains of the platinum aluminide.

[0011] The coating of this first aspect may be referred to as a platinum aluminide coating. Suitably the coating is a modified platinum aluminide - a platinum aluminide modified by the inclusion of other species, such as the chromium and silicon. Suitably the platinum aluminide comprises chromium, aluminium, platinum and silicon. A platinum aluminide coating provides corrosion protection by forming a protective layer of aluminium oxide through the oxidation of the aluminium in the coating, in use. However, this aluminium oxide layer is vulnerable to cracking and spallation, leading to failure of the protective coating and exposure of the bulk material of the component (the substrate) to corrosion processes. This ultimately leads to a shortened operational lifetime of the component.

[0012] The inventors have found that this problem can be addressed by using a mixture of fine and coarse grains of the platinum aluminide as a coating. The fine grains of the platinum aluminide provide the coating with good fatigue properties which is beneficial in enhancing the

low cycle fatigue resistance of the component. However, cracks may initiate in such fine grains of platinum aluminide. The inventors have found that providing the coarse grains of platinum aluminide along with the fine grains of platinum aluminide may have the beneficial effect of slowing down or preventing the propagation of such cracks, improving the resistance of the coating to mechanical failure. Therefore the combination of fine and coarse grains of the platinum aluminide coating of this first aspect of the present invention may provide enhanced fracture toughness (resistance to fractures and crack propagation) as well as low cycle fatigue resistance, whilst providing resistance to hot corrosion processes.

[0013] Suitably the fine grains of the platinum aluminide have a particle size of less than 30 μm . Suitably the coarse grains of the platinum aluminide have a particle size greater than 30 μm . Suitably the fine grains of the platinum aluminide have a particle size of less than 30 μm and the coarse grains of the platinum aluminide have a particle size greater than 30 μm .

[0014] Suitably the fine grains of the platinum aluminide have a particle size of less than 25 μm , suitably less than 20 μm , suitably less than 15 μm .

[0015] Suitably the fine grains of the platinum aluminide have a particle size of greater than 1 μm , suitably greater than 2 μm , suitably greater than 5 μm .

[0016] The fine grains of the platinum aluminide may have a particle size of from 5 μm to 15 μm .

[0017] Suitably the coarse grains of the platinum aluminide have a particle size of less than 100 μm , suitably less than 75 μm , suitably less than 50 μm .

[0018] The coarse grains of the platinum aluminide may have a particle size of from 30 μm to 50 μm .

[0019] The coating of this first aspect may comprise grains of platinum aluminide with an intermediate particle size. For example, the coating may comprise fine grains of platinum aluminide having a particle size of from 5 μm to 15 μm , coarse grains of platinum aluminide having a particle size of from 30 μm to 50 μm and intermediate grains of platinum aluminide having a particle size of from 30 μm to 50 μm .

[0020] The grain sizes of the platinum aluminide are suitably measured through standard techniques as described in ASTM standards, for example ASTM E112-13. The grain size may be measured using typical equipment in state of the art, for example using a scanning electron microscope (SEM).

[0021] The inventors have found that such a range of particle sizes can provide a platinum aluminide coating with the favourable chemical (anti-corrosion) and mechanical properties discussed above. The inventors have also found that such a range of particle sizes can be mixed in different ratios to provide different regions of the coating with differing chemical or mechanical properties, according to the specific requirements in those regions of the coating on a component.

[0022] Suitably the fine grains, coarse grains and op-

tionally intermediate grains of platinum aluminide are thoroughly mixed together in the coating. Therefore the fine grains, coarse grains and optionally intermediate grains of platinum aluminide may be considered to be randomly distributed in the coating.

[0023] Suitably the coating consists of and/or consists essentially of the fine grains, coarse grains and optionally intermediate grains of platinum aluminide.

[0024] Suitably the ratio of fine grains to coarse grains of the platinum aluminide in the coating is from 10:1 to 1:10.

[0025] In some embodiments, the ratio of fine grains to coarse grains of the platinum aluminide in the coating is from 5:1 to 1:1, suitably from 4:1 to 2:1, suitably approximately 3:1.

[0026] The inventors have found that such a mixture of fine grains and coarse grains of platinum aluminide in the coating may provide both low cycle fatigue resistance and good crack propagation resistance, whilst also providing resistance to corrosion, specifically resistance to Type II hot corrosion. These properties may be beneficial in certain regions of certain components, for example in a bottom region of a turbine aerofoil between a platform and a root.

[0027] In some embodiments, the coating comprises a first region and a second region, wherein the first region and the second region comprise different amounts of fine grains of the platinum aluminide and/or different amounts of the coarse grains of the platinum aluminide. For example the first region of the coating may have the ratio of fine grains to coarse grains discussed above. The second region of the coating may have a higher ratio of fine grains to coarse grains of the platinum aluminide (therefore a lower proportion of coarse grains than in the first region). The second region may comprise mainly fine grains, suitably only fine grains of the platinum aluminide. The second region of the coating may be located on a component which requires only low cycle fatigue resistance and not crack propagation resistance, for example in a turbine aerofoil root.

[0028] The coating of this first aspect may have a composition gradient across at least one dimension of the coating, suitably between the first region and the second region.

[0029] Suitably the composition gradient is a gradual change in composition from the first region to the second region of the coating. Such a composition gradient may be distinct from a step change in composition between different regions in coatings formed from different platinum aluminide compositions.

[0030] Suitably the platinum aluminide coating in the first region of the coating and the platinum aluminide coating of the second region of the coating are similar and suitably vary in the proportions of fine grains, coarse grains and optionally any other grain size of platinum aluminide present, for example intermediate sized grains. Suitably the chemical composition of the platinum aluminide coating in the first and second regions is the

same.

[0031] Suitably the different platinum aluminide coatings in different regions of the coating, for example the first and second regions, are mixed with the adjacent region at an interface region.

[0032] The inventors have found that such a mixing of adjacent platinum aluminide coatings (having different grain size distributions) at different regions of the coating provides a more gradual change in composition and properties from one region to the adjacent region than would otherwise be possible. This may also provide a stronger bond between adjacent regions than if the coating had a step change in platinum aluminide coating composition between regions.

[0033] Suitably the coating has a composition gradient along the length of the coating, on a suitable component.

[0034] Suitably the chemical compositions of the fine grains, coarse grains and optionally intermediate grains of platinum aluminide are the same. Therefore the fine grains, coarse grains and optionally intermediate grains of platinum aluminide suitably comprise the same amounts of chromium, aluminium, platinum and silicon, and any other metals present.

[0035] Suitably the platinum aluminide coating of this first aspect comprises at least 25 wt% platinum, suitably at least 30 wt% platinum, suitably at least 35 wt% platinum.

[0036] Suitably the platinum aluminide coating comprises up to 50 wt% platinum, suitably up to 45 wt% platinum, suitably up to 40 wt% platinum.

[0037] Suitably the platinum aluminide coating comprises from 25 to 50 wt% platinum, suitably from 30 to 45 wt% platinum, suitably from 35 to 45 wt% platinum..

[0038] Suitably the platinum aluminide coating comprises at least 5 wt% aluminium, suitably at least 10 wt% aluminium, suitably at least 15 wt% aluminium.

[0039] Suitably the platinum aluminide coating comprises up to 35 wt% aluminium, suitably up to 30 wt% aluminium, suitably up to 25 wt% aluminium.

[0040] Suitably the platinum aluminide coating comprises from 10 to 30 wt% aluminium, suitably from 12 to 30 wt% aluminium, suitably from 15 to 25 wt% aluminium, for example approximately 20 wt% aluminium or 20 wt% aluminium.

[0041] Suitably the platinum aluminide coating comprises at least 1 wt% chromium, suitably at least 2 wt% chromium, suitably at least 5 wt% chromium.

[0042] Suitably the platinum aluminide coating comprises up to 30 wt% chromium, suitably up to 25 wt% chromium, suitably up to 20 wt% chromium.

[0043] Suitably the platinum aluminide coating comprises from 1 to 30 wt% chromium, suitably from 2 to 25 wt% chromium, suitably from 5 to 20 wt% chromium, for example approximately 12 wt% chromium or 12 wt% chromium.

[0044] Suitably the platinum aluminide coating comprises from 0.5 to 10 wt% silicon, suitably from 1 to 5 wt% silicon, suitably from 2 to 5 wt% silicon, for example ap-

proximately 3 wt% silicon or 3 wt% silicon.

[0045] Suitably the platinum aluminide coating comprises from 2 to 25 wt% chromium, from 12 to 30 wt% aluminium, from 10 to 50 wt% platinum and from 1 to 5 wt% silicon.

[0046] In some embodiments, the platinum aluminide coating may comprise one or more of rhodium, yttrium, hafnium, lanthanum and zirconium. Suitably the platinum aluminide coating comprises at least one of yttrium, hafnium or zirconium. For example, the platinum aluminide coating may comprise yttrium and zirconium.

[0047] In said embodiments, the platinum aluminide coating may comprise from 0.01 to 5 wt% yttrium, hafnium or zirconium, suitably from 0.1 to 3 wt% yttrium, hafnium or zirconium, suitably from 0.5 to 2 wt% yttrium, hafnium or zirconium. Suitably the platinum aluminide coating comprises yttrium and zirconium in the above amounts.

[0048] Suitably the platinum aluminide comprises from 0.1 to 5wt% hafnium, from 0.1 to 3 wt% yttrium and from 0.1 to 3 wt% zirconium.

[0049] Suitably the platinum aluminide coating comprises from 2 to 25 wt% chromium, from 12 to 30 wt% aluminium, from 10 to 50 wt% platinum, from 1 to 5 wt% silicon, from 0.1 to 5 wt% hafnium, from 0.1 to 3 wt% yttrium and from 0.1 to 3 wt% zirconium.

[0050] Suitably nickel provides the balance (to a total of 100 wt%) in the platinum aluminide coatings described above.

[0051] Suitably the platinum aluminide coating consists of and/or consists essentially of from 2 to 25 wt% chromium, from 12 to 30 wt% aluminium, from 10 to 50 wt% platinum, from 1 to 5 wt% silicon, from 0.1 to 5 wt% hafnium, from 0.1 to 3 wt% yttrium, from 0.1 to 3 wt% zirconium and nickel to balance.

[0052] In some embodiments of the coating of this first aspect, the platinum aluminide coating may comprise platinum aluminide particles having a different shape to the fine and coarse grains of platinum aluminide. For example, the platinum aluminide coating may comprise spherical particles of the platinum aluminide and rectangular particles of the platinum aluminide.

[0053] The inventors have found that introducing particles of platinum aluminide having a different shape to the fine and coarse grains of platinum aluminide may provide a further improvement in crack propagation resistance of the platinum aluminide coating, in regions of the coating where said particles of platinum aluminide are present.

[0054] Suitably the thickness of the platinum aluminide coating, for example on a component, is from 10 to 30 μm .

[0055] In some embodiments, the platinum of the platinum aluminide may be replaced by a different noble metal, for example a different platinum-group metal. Suitably the different platinum group metal is selected from ruthenium, rhodium, palladium, osmium and iridium or a combination thereof, optionally with platinum. In said embodiments, the amounts of the different noble metal(s)

present in the aluminide are as described above for platinum.

[0056] According to a second aspect of the present invention, there is provided a component comprising a coating according to the first aspect.

[0057] Suitably the component comprises a substrate onto which the platinum aluminide coating of the first aspect is provided on at least one region of the component.

[0058] In the component of this second aspect, the substrate forms the bulk of the component and the platinum aluminide coating of the first aspect forms a protective coating on the component. Suitably the platinum aluminide coating provides an outermost layer of the component which is exposed to the environment outside of the component, in use. Suitably the platinum aluminide coating completely covers and surrounds the substrate.

[0059] Suitably the component is formed from a nickel alloy, suitably a nickel superalloy. Therefore the substrate of the component is suitably a nickel alloy, suitably a nickel superalloy.

[0060] In some embodiments, the component is a turbine aerofoil comprising a tip, a blade, a platform and a root; wherein the platinum aluminide coating according to the first aspect is located in a bottom region of the turbine aerofoil between the platform and the root.

[0061] The inventors have found that such a bottom region of a turbine aerofoil is particularly susceptible to low cycle fatigue and/or coating cracking, when coated with coating systems of the prior art. The inventors have also found that the coating of the first aspect may provide such a bottom region of a turbine aerofoil with low cycle fatigue resistance whilst the coating resists crack propagation in the coating. The coating of the first aspect may also provide resistance to corrosion, specifically resistance to Type II hot corrosion which is the prevalent corrosion process suffered in such a bottom region of the turbine aerofoil, in use.

[0062] The component of this second aspect may have a first region and a second region having the platinum aluminide coating, with the first and second regions being as described in relation to the first aspect. In embodiments wherein the component of this second aspect is a turbine aerofoil comprising a tip, a blade, a platform and a root, and wherein the platinum aluminide coating according to the first aspect is located in a bottom region of the turbine aerofoil between the platform and the root, the first region may be the bottom region and the second region may be the root. Suitably the platinum aluminide coating of the bottom region of the component has the ratio of fine grains to coarse grains of platinum aluminide discussed above in relation to the first aspect. Suitably the platinum aluminide coating of the root comprises only fine grains of the platinum aluminide. The inventors have found that such a turbine aerofoil has the aforementioned beneficial properties in the bottom (first) region and only the required low cycle fatigue resistance in the root (second) region.

[0063] The component of this second aspect may com-

prise further regions having different amounts of fine grains and/or coarse grains of the platinum aluminide and/or different ratios of fine grains to coarse grains of the platinum aluminide in the coating, compared to the first and/or second regions. For example, the bottom region of a turbine aerofoil may comprise different sub-regions having different amounts of fine grains and/or coarse grains of the platinum aluminide and/or different ratios of fine grains to coarse grains of the platinum aluminide in the coating, according to the environmental conditions to which that sub-region is exposed to in use and/or according to the particular mechanical properties required at that sub-region.

[0064] In some embodiments, a turbine aerofoil may be coated with the platinum aluminide coating of this first aspect at a region comprising the tip of the turbine aerofoil, for example a region extending from the tip to 10 mm below the tip.

20 Method of coating

[0065] According to a third aspect of the present invention, there is provided a method of coating a component with a platinum aluminide, the method comprising the steps of:

a) applying fine grains of at least one constituent of the platinum aluminide onto the component;

b) applying coarse grains of at least one constituent of the platinum aluminide onto the component.

[0066] Suitably steps a) and b) are carried out in a single coating operation.

[0067] Suitably the method of this third aspect provides a coating according to the first aspect and/or a component according to the second aspect. The component and platinum aluminide coating of this third aspect may have any of the features or advantages of the component and platinum aluminide coating referred to in relation to the first and second aspects.

[0068] Steps a) and b) are carried out in a single coating operation. Suitably a single coating operation is when the coating method is uninterrupted by, for example, changing coating compositions, changing coating apparatus, masking off a region of the component, removing a masking from a region of the component or removing the component from the coating apparatus.

[0069] The at least one constituent of the platinum aluminide may be one or more of the metallic elements which are present in the platinum aluminide coating of the first aspect. In some embodiments, the at least one constituent of the platinum aluminide coating is one constituent, suitably one metallic element, for example platinum. In alternative embodiments, the at least one constituent of the platinum aluminide is all of the constituents of the platinum aluminide, therefore the complete platinum aluminide coating composition.

[0070] Suitably steps a) and b) are carried out simultaneously by applying a mixture of fine grains of the at least one constituent of the platinum aluminide and coarse grains of the at least one constituent of the platinum aluminide onto the component.

[0071] Suitably the method of this third aspect is carried out on a bottom region of a turbine aerofoil, as described herein.

[0072] Suitably the coating of the component, including steps a) and b), is carried out according to a computer model of the component. Suitably a computer model of the component is generated before the method of coating is carried out. The computer model may contain information regarding what specific mixture of fine and coarse grains of the at least one constituent of the platinum aluminide coating is to be applied to which region of the component, according to what chemical and/or mechanical properties have been determined to be necessary for each region. Therefore the platinum aluminide coating may be tailored to the requirements of the component being coated, for example according to an analysis of corrosion processes and mechanical stresses suffered by the component in particular regions of the component, in use.

Layered deposition

[0073] In some embodiments of the method of this third aspect, the fine and coarse grains of platinum aluminide are formed on the component after steps a) and b) of applying fine and coarse grains of at least one constituent of the platinum aluminide onto the component. Steps a) and b) may be carried out by electroplating.

[0074] In said embodiments, steps a) and b) may be followed by a heat treatment step, suitably a low temperature heat treatment step, for example at a temperature of up to 600 °C. The heat treatment step may improve the bonding of the at least one constituent of the platinum aluminide applied in steps a) and b) onto the component (i.e. the substrate), in particular when the at least one constituent of the platinum aluminide applied in steps a) and b) is platinum.

[0075] In said embodiments, the constituents (elements) of the coating may be applied individually. Suitably steps a) and b) involve applying fine and coarse grains of one constituent of the platinum aluminide, followed by a step c) of applying the remaining constituents of the platinum aluminide. Said remaining constituents of the platinum aluminide may be applied individually and sequentially to the component. Alternatively, step c) may be carried out by applying a powder mixture of all of said remaining constituents of the platinum aluminide. Step c) may be carried out by cold spraying a powder mixture of said remaining constituents of the platinum aluminide.

[0076] Suitably said step c) is followed by a step d) of interdiffusion heat treatment. Step d) suitably interdiffuses the constituents applied in steps a) and b) with the constituents of the platinum aluminide applied in step c)

to provide the coating of platinum aluminide. Suitably step d) of interdiffusion heat treatment is carried out at a temperature of from 1,030 to 1,080 °C, suitably for a time of from 4 and 20 hours.

[0077] Suitably step d) causes the constituents of the platinum aluminide applied in step c) to interdiffuse into the fine and coarse grains of the constituent of the platinum aluminide applied in steps a) and b), which is suitably platinum, to provide fine and coarse grains of platinum aluminide. This interdiffusion may cause the size of the fine and coarse grains to change, for example by recrystallization. However, despite this potential change in size, the fine and coarse grains suitably retain the size ranges described in relation to the first aspect.

[0078] Suitably the one constituent of the platinum aluminide applied in steps a) and b) is platinum. Suitably step c) involves applying a mixture of aluminium, chromium, hafnium, zirconium and silicon (when present) to the platinum.

[0079] The inventors have found that in said embodiments, the platinum aluminide coating may have a more favourable ductility than in embodiments wherein the platinum aluminide is applied in one stage, for example as a pre-alloyed powder.

[0080] Suitably this third aspect provides a method of coating a component with a platinum aluminide comprising chromium, aluminium, platinum and silicon, the method comprising the steps of:

a) applying fine grains of platinum onto the component;

b) applying coarse grains of platinum onto the component;

c) applying a powder mixture composition comprising chromium, aluminium and silicon by cold spraying; and

d) heat treating the component to interdiffuse the composition comprising chromium, aluminium and silicon into the fine and coarse grains of platinum to provide fine and coarse grains of the platinum aluminide.

[0081] In some embodiments of the method of this third aspect, the fine and coarse grains of platinum aluminide are directly applied to the component as pre-alloyed powders. Therefore in said embodiments, step a) involves applying fine grains of the platinum aluminide onto the component and step b) involves applying coarse grains of the platinum aluminide onto the component.

Cold spraying

[0082] In some embodiments of the method of this third aspect, steps a) and b) are carried out by a cold spray apparatus. Suitably steps a) and b) are carried out simul-

taneously by a single cold spray apparatus.

[0083] The inventors have found that the method of this second aspect can be carried out without masking off different parts of the component being coated. Suitably the method of this second aspect does not comprise a masking off step. Suitably the method does not comprise a masking off step between step a) and step b). Avoiding such masking off steps can provide a much more efficient coating process and so improve the efficiency of the component manufacture.

[0084] The inventors have also found that cold spraying a platinum aluminide powder of fine grain size produces a heavily cold-worked coating that subsequently creates nano sized sub-grains that ultimately result in a fine grain microstructure with good low cycle fatigue properties.

[0085] In said embodiments, the method suitably involves mixing powders of platinum aluminide coating material having different particle sizes from at least two powder storage vessels to provide the coating of platinum aluminide.

[0086] Suitably the method of this third aspect is carried out on a bottom region of a turbine aerofoil, suitably between a platform and a root of the turbine aerofoil.

[0087] In some embodiments, the method of this third aspect involves cold spraying further coating compositions onto further regions of the component.

[0088] According to a fourth aspect of the present invention, there is provided an apparatus for coating a component, the apparatus comprising:

at least one cold spray unit;

a carrier gas supply arranged in communication with the at least one cold spray unit;

at least two powder storage vessels each arranged in communication with the at least one cold spray unit; and

a control unit;

wherein the at least two powder storage vessels are each provided with a metering device for controlling flow of powder from the powder storage vessels to the at least one cold spray unit; and

wherein the control unit is adapted to control the metering devices and the at least one spray unit.

[0089] The apparatus of this fourth aspect may be adapted to carry out a method of the third aspect and/or to provide a component according to the second aspect.

[0090] A suitable cold spray unit comprises a convergent-divergent nozzle for directing powder compositions, accelerated by said carrier gas, to a surface of a component to be coated (a target substrate). The apparatus suitably comprises more than one cold spray unit. For

example, in some embodiments the apparatus comprises two cold spray units. In some embodiments, the apparatus comprises more than two cold spray units. For example, in some embodiments the apparatus comprises three cold spray units.

[0091] Suitably the apparatus of this fourth aspect is adapted to combine powders from the at least two powder storage vessels to form a powder coating composition for coating onto a component.

[0092] In some embodiments, the at least two powder storage vessels are each arranged in communication with the different cold spray units (of the "at least one cold spray unit" of the apparatus). Therefore in such embodiments, the apparatus comprises at least two cold spray units which are each arranged in communication with different powder storage vessels (of the "at least two powder storage vessels" of the apparatus). By "arranged in communication with" we mean that the stated parts of the apparatus are able to have powder transferred between them.

[0093] During use of said embodiments of the apparatus, the at least two powder storage vessels may each be provided with a different powder coating composition, for example a different mixture of fine and coarse grains of platinum aluminide material, which may then be coated onto different regions of said component by the different cold spray units. Therefore a component can be provided with a coating having a different composition of fine and coarse grains of platinum aluminide material in different regions of said component.

[0094] In some embodiments, the at least two powder storage vessels are each arranged in communication with the same cold spray unit (of the "at least one cold spray unit" of the apparatus). Therefore in such embodiments, the apparatus comprises at least one cold spray unit which is arranged in communication with the at least two powder storage vessels.

[0095] During use of said embodiments of the apparatus, the at least two powder storage vessels may each be provided with a different grain size range of platinum aluminide material, for example fine grains in a first powder storage vessel and coarse grains in a second powder storage vessel, which are then mixed according to the operation of the metering devices of the at least two powder storage vessels to provide a mixture of fine and coarse grains of platinum aluminide material which may then be coated onto a region of said component by the cold spray unit. The cold spray unit may then be moved relative to the component and the metering devices operate to mix said platinum aluminide material in the at least two storage vessels to provide a different mixture of fine and coarse grains of platinum aluminide material which is then coated onto a different region of said component. Therefore a component can be provided with a coating having a different mixture of fine and coarse grains of platinum aluminide material composition in different regions of said component, using a single cold spray unit.

[0096] The fine and coarse grains of platinum aluminide material referred to above may have any of the suitable features and advantages of the fine and coarse grains of platinum aluminide referred to in relation to the first aspect.

[0097] The apparatus may comprise a third powder storage vessel which may be charged, in use, with intermediate sized grains of platinum aluminide material, as described in relation to the first aspect. The apparatus may also comprise a fourth powder storage vessel which may be charged, in use, with particles of platinum aluminide material having a different shape to the fine, coarse and/or intermediate sized grains of platinum aluminide material, as described in relation to the first aspect. Therefore the apparatus may operate to provide the intermediate sized grains of platinum aluminide and/or the particles of platinum aluminide having a different shape, to the mixtures applied to said component by the cold spray unit.

[0098] Suitably the control unit is programmable with a computer model of said component and the control unit is adapted to activate the apparatus to provide particular coating compositions onto particular regions of said component according to said computer model.

Brief Description of the Drawings

[0099] Examples of the present disclosure will now be described with reference to the accompanying drawings, in which:

Figure 1 is a schematic of a coating according to the first aspect of the present invention;

Figure 2 is a perspective view of a component according to the second aspect of the present invention, having a coating; and

Figure 3 is a schematic of a cold spray apparatus according to the fourth aspect of the present invention being used to carry out a method according to the third aspect of the present invention.

Detailed Description

[0100] Figure 1 shows a schematic of a platinum aluminide coating (100) according to the first aspect applied to a substrate (110) of a component. The substrate (110) is formed from a nickel alloy known in the art, for example a nickel alloy commonly used to construct turbine components such as turbine aerofoils, for example a nickel superalloy. The platinum aluminide coating (100) is the outermost layer of the component which is exposed to the environment in use. The platinum aluminide coating (100) comprises from 2 to 25 wt% chromium, from 12 to 30 wt% aluminium, from 10 to 50 wt% platinum, from 1 to 5 wt% silicon, from 0.1 to 5 wt% hafnium, from 0.1 to 3 wt% yttrium, from 0.1 to 3 wt% zirconium and nickel to

balance. The platinum aluminide coating (100) comprises a mixture of fine and coarse grains of the above platinum aluminide composition. The platinum aluminide coating (100) comprises from 40 to 50 wt% of fine grains of platinum aluminide material having particle sizes in the range of 5 to 15 μm , from 20 to 30 wt% of intermediate sized grains of platinum aluminide material having particle sizes in the range of from 15 to 30 μm and from 10 to 20 wt% of coarse grains of platinum aluminide material having particle sizes in the range of from 30 to 50 μm . This platinum aluminide coating (100) may provide the substrate with enhanced fracture toughness (resistance to fractures and crack propagation) as well as low cycle fatigue resistance, whilst providing resistance to hot corrosion processes.

[0101] Figure 2 shows component (200) which is a turbine aerofoil formed of a substrate of nickel superalloy and a coating. The component (200) comprises a first region (210), a second region (220), a platform (230), a root (240) and a tip (250), which are common parts of such turbine aerofoils with known functions. The first region (210) of the component (200) extends from beneath the platform (230) to the top of the root (240). This first region (210) has the platinum aluminide coating (100) shown in Figure 1 as described above. The operating temperatures experienced by the first region (210) of component (100) are in the region of 600-650 °C which causes Type II hot corrosion of such nickel alloy components. The platinum aluminide coating (100) may provide good resistance against this type of hot corrosion, which would otherwise result in damage to and potentially failure of the component (100) in use. The platinum aluminide coating (100) may also provide enhanced fracture toughness (resistance to fractures and crack propagation) as well as low cycle fatigue resistance. The second region (220) of the component comprises the root and has a platinum aluminide coating comprising only fine grains of the platinum aluminide having particle sizes in the range of 5 to 15 μm . The platinum aluminide coating in the second region (220) of the component may provide the root with enhanced low cycle fatigue resistance. In said second region comprising the root, enhanced resistance to fractures and crack propagation is generally not required.

Formation of the coating by cold spray

[0102] Component (200) can be coated with the platinum aluminide coating described above in relation to the first and second regions (210 and 220) using methods known in the art, for example by masking off the second region of the component whilst the first region of the component is being provided with the required platinum aluminide coating. Masking off certain regions of the component adds cost and complexity to the coating process. Other known methods of coating the component, such as pack aluminide, chemical vapour deposition, high-velocity oxy-fuel and electron beam physical vapour depo-

sition, may involve the use of high temperatures. Such high temperatures typically result in localized stresses in the component substrate material when the coating cools down, which may cause significant thermal distortion of the component.

[0103] Component (200) may be coated using cold spraying which may have significant advantages over other known coating methods. The main components of a cold spray apparatus are well known in the state of the art and include a powder storage vessel which stores and supplies powder coating material, a carrier gas supply for accelerating the powder materials, a mixing chamber and a convergent-divergent nozzle. During use of such a cold spray apparatus, powder particles strike the target surface causing a plastic deformation of the powder particles which ultimately results in the particles forming a strong bond with the target surface.

[0104] The powder coating materials used for cold spraying typically have a particle size (diameter) of 5-80 μm . Using smaller particle sizes enables higher particle velocities to be attained. Smaller particle sizes are used if the powder coating material is relatively hard. The powder coating materials are accelerated to supersonic velocities using compressed gas which is normally selected from helium, nitrogen or another inert gas.

[0105] As the powder coating materials are not heated to high temperatures during the cold spraying process, oxidation and/or degradation of the powder coating materials does not occur. Also, as relatively low temperatures are used in cold spraying compared to other known coating methods, thermal distortion of the component substrate material is substantially reduced. Another significant advantage of using cold spraying is the formation of significant compressive residual stress in the component which has the added benefit of improved life and mechanical integrity of the component. Furthermore, coating by cold spraying does not require the masking off of regions of the component which are not intended to be coated with a particular coating composition due to the very small stand-off distances between the cold spray apparatus and the target substrate. The removal of the requirement for masking off may provide a more efficient coating process and also avoid geometrical discontinuities between different coating regions of the component which may otherwise be produced by other known coating methods.

[0106] However, the cold spray methods of the prior art are not able to provide to a component, in a single coating step, a coating having a different distribution of grain sizes in different regions of the component. The cold spray apparatus (300) of Figure 3 can overcome this drawback of the cold spray apparatus of the prior art.

[0107] Cold spray apparatus (300) comprises three cold spray units (311, 312 and 313), three powder storage vessels (321, 322 and 323) and a control unit (340). The three cold spray units (311, 312 and 313) are each arranged in communication with a carrier gas supply (314) for accelerating powder coating material from the powder

storage vessels towards a target substrate (component (200)). The three cold spray units (311, 312 and 313) are each arranged in communication with each of the three powder storage vessels (321, 322 and 323) for transfer of powder coating material from the powder storage vessels (321, 322 and 323) to the cold spray units (311, 312 and 313).

[0108] The three powder storage vessels (321, 322 and 323) are each provided with a metering device (331, 332 and 333) for controlling flow of powder coating material from the powder storage vessels (321, 322 and 323) to the three cold spray units (311, 312 and 313).

[0109] The control unit (340) is adapted to control the operation of the metering devices (331, 332 and 333) and therefore control the flow of powder coating material from the powder storage vessels (321, 322 and 323) to the three cold spray units (311, 312 and 313). The control unit (340) is also adapted to control the operation of the three cold spray units (311, 312 and 313). The powder coating material provided to the powder storage vessels may be grains of platinum aluminide material, as described above.

[0110] The control unit (340) is adapted to control the metering devices (331, 332 and 333) and the three cold spray units (311, 312 and 313) to carry out a method of coating a component (200) according to a computer model of the coating and the component (400) programmed into the control unit (340). The cold spray apparatus (300) can therefore provide component (200) with a coating having a different distribution of grain sizes of platinum aluminide coating in different regions of the component, for example a first region (210) and a second region (220) as described above in relation to Figure 2, in a single coating operation. This cold spray method and apparatus may therefore efficiently provide a component with a platinum aluminide coating tailored in specific regions of the component to resist the specific corrosion mechanisms and/or to improve the mechanical properties of the component in those regions, in order to improve the performance and prolong the useful life of the component.

[0111] The three powder storage vessels (321, 322 and 323) may each be provided with a different grain size of platinum aluminide material which forms the platinum aluminide coating (100) according to first aspect of the present invention, when combined and applied to a component by the cold spray apparatus (200). In such embodiments, the control unit (340) determines the amount of each of said different grain sizes of platinum aluminide material to combine to form a powder coating mixture, by appropriate activation of the metering devices (321, 322 and 323), to provide said powder coating mixture to the appropriate cold spray unit for cold spraying onto the appropriate region of the component (200). For example, one of the three powder storage vessels (321) may be charged with fine grains of platinum aluminide material having particle sizes in the range of 5 to 15 μm . Another of the three powder storage vessels (322) may be charged with intermediate sized grains of platinum alu-

minide material having particle sizes in the range of from 15 to 30 μm . Another of the three powder storage vessels (323) may be charged with coarse grains of platinum aluminide material having particle sizes in the range of from 30 to 50 μm . The fine, intermediate and coarse grains of platinum aluminide material may then be supplied from the separate powder storage vessels to the cold spray units in proportions appropriate to provide the platinum aluminide coating (100) in the first region (210) of the component (200) and to provide the desired platinum aluminide coating in further regions of the component.

[0112] Alternatively the three powder storage vessels (321, 322 and 323) may each be provided with a pre-mixed combination of fine, coarse and/or intermediate sized grains of platinum aluminide material corresponding to a coating intended for a specific region of the component (200). In such embodiments, the control unit (340) determines, by appropriate activation of the metering devices (321, 322 and 323), which of said powder coating mixtures to provide to the appropriate cold spray unit for cold spraying onto the appropriate region of the component (200). For example, a powder coating composition corresponding to the platinum aluminide coating (100), may be charged into a powder storage vessel. This powder coating composition can then be supplied from the powder storage vessel to one of the cold spray units to provide the platinum aluminide coating (100) in the first region (210) of the component (200).

[0113] The cold spray apparatus (200) may contain more than three cold spray units and/or powder storage vessels to enable further options for combining or providing different powder coating ingredients or mixtures onto different regions of a component. For example, a further powder storage vessel may be charged with platinum aluminide particles having a different shape to the fine, coarse and intermediate grains of platinum aluminide, as discussed above.

[0114] Alternatively, component (200) may be coated by first electroplating a mixture of fine and coarse grains of platinum onto the component (200). Suitable electroplating techniques are well known in the state of the art. This electroplating may then be followed by cold spraying the remaining constituents of the platinum aluminide in a similar way to that described above, wherein different constituents of the platinum aluminide or different mixtures of the remaining constituents of the platinum aluminide are charged into the powder storage vessels and mixed accordingly to provide the desired quantities of each constituent of the platinum aluminide. An interdiffusion heat treatment step is then carried out to form the fine and coarse grains of platinum aluminide.

[0115] In summary, the present invention provides a coating for a component, such as a turbine aerofoil, which may provide said component with corrosion resistance and which may also provide enhanced resistance to fractures and crack propagation as well as low cycle fatigue resistance. The coating is a platinum aluminide comprising chromium, aluminium, platinum and silicon. The coat-

ing is formed of fine grains of the platinum aluminide and coarse grains of the platinum aluminide. The coating may provide an effective outermost coating on said component. The present invention also provides a component comprising such a coating, a method of forming such a coating on a component and a cold spraying apparatus for applying such a coating. Furthermore the relative amounts of fine and coarse grains can be altered in different regions of the coating to provide chemical and/or mechanical properties which are tailored to the requirements in particular regions of a component.

[0116] Throughout this specification, the term "comprising" or "comprises" means including the component(s) specified but not to the exclusion of the presence of other components. The term "consisting essentially of" or "consists essentially of" means including the components specified but excluding other components except for materials present as impurities, unavoidable materials present as a result of processes used to provide the components, and components added for a purpose other than achieving the technical effect of the invention. Typically, when referring to compositions, a composition consisting essentially of a set of components will comprise less than 5% by weight, typically less than 3% by weight, more typically less than 1% by weight of non-specified components.

[0117] The term "consisting of" or "consists of" means including the components specified but excluding addition of other components.

[0118] Whenever appropriate, depending upon the context, the use of the term "comprises" or "comprising" may also be taken to encompass or include the meaning "consists essentially of" or "consisting essentially of", and may also be taken to include the meaning "consists of" or "consisting of".

[0119] For the avoidance of doubt, wherein amounts of components in a composition are described in wt%, this means the weight percentage of the specified component in relation to the whole composition referred to. For example, "the platinum aluminide coating comprises at least 30 wt% platinum" means that 30 wt% of the platinum aluminide coating is provided by platinum.

[0120] Attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

[0121] All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

[0122] Each feature disclosed in this specification (including any accompanying claims, abstract and drawings) may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly

stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

[0123] The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

Claims

1. A coating for a component, wherein the coating is a platinum aluminide and wherein the coating comprises fine grains of the platinum aluminide and coarse grains of the platinum aluminide. 15
2. The coating according to claim 1, wherein the fine grains of the platinum aluminide have a particle size of less than 30 μm and the coarse grains of the platinum aluminide have a particle size greater than 30 μm . 20
3. The coating according to claim 1 or claim 2, wherein the ratio of fine grains to coarse grains of the platinum aluminide in the coating is from 10:1 to 1:10. 25
4. The coating according to any preceding claim, wherein the coating comprises a first region and a second region, wherein the first region and the second region comprise different amounts of fine grains of the platinum aluminide and/or different amounts of the coarse grains of the platinum aluminide. 30 35
5. The coating according to any preceding claim, wherein the platinum aluminide comprises from 2 to 25 wt% chromium, from 12 to 30 wt% aluminium, from 10 to 50 wt% platinum and from 1 to 5 wt% silicon. 40
6. The coating according to any preceding claim, wherein the platinum aluminide comprises at least one of yttrium, hafnium or zirconium. 45
7. The coating according to claim 6, wherein the platinum aluminide comprises from 0.1 to 5 wt% hafnium, from 0.1 to 3 wt% yttrium and from 0.1 to 3 wt% zirconium. 50
8. A component comprising a coating according to any one of claims 1 to 7.
9. The component of claim 8, wherein the component is a turbine aerofoil comprising a tip, a blade, a platform and a root; wherein the coating according to any one of claims 1 to 7 is located in a bottom region 55

of the turbine aerofoil between the platform and the root.

10. A method of coating a component with a platinum aluminide, the method comprising the steps of: 5
 - a) applying fine grains of at least one constituent of the platinum aluminide onto the component;
 - b) applying coarse grains of at least one constituent of the platinum aluminide onto the component. 10
11. The method according to claim 10, wherein steps a) and b) are followed by a step c) of applying the remaining constituents of the platinum aluminide. 15
12. The method according to claim 10 or claim 11, wherein steps a) and b) are carried out simultaneously by applying a mixture of fine and coarse grains of the at least one constituent of the platinum aluminide onto the component. 20
13. The method according to any one of claims 9 to 12, wherein the coating of the component, including steps a), b) and c), when present, is carried out according to a computer model of the component. 25
14. An apparatus for coating a component, the apparatus comprising:
 - at least one cold spray unit;
 - a carrier gas supply arranged in communication with the at least one cold spray unit;
 - at least two powder storage vessels each arranged in communication with the at least one cold spray unit; and
 - a control unit;
 - wherein the at least two powder storage vessels are each provided with a metering device for controlling flow of powder from the powder storage vessels to the at least one cold spray unit; and
 - wherein the control unit is adapted to control the metering devices and the at least one spray unit. 30 35 40 45
15. The cold spray unit according to claim 14, wherein the control unit is programmable with a computer model of said component and wherein the control unit is adapted to activate the apparatus to provide particular coating compositions onto particular regions of said component according to said computer model. 50

FIG 1

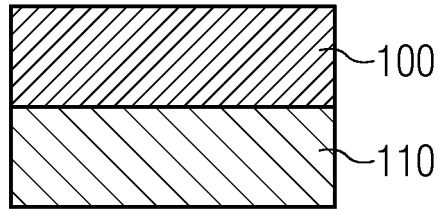


FIG 2

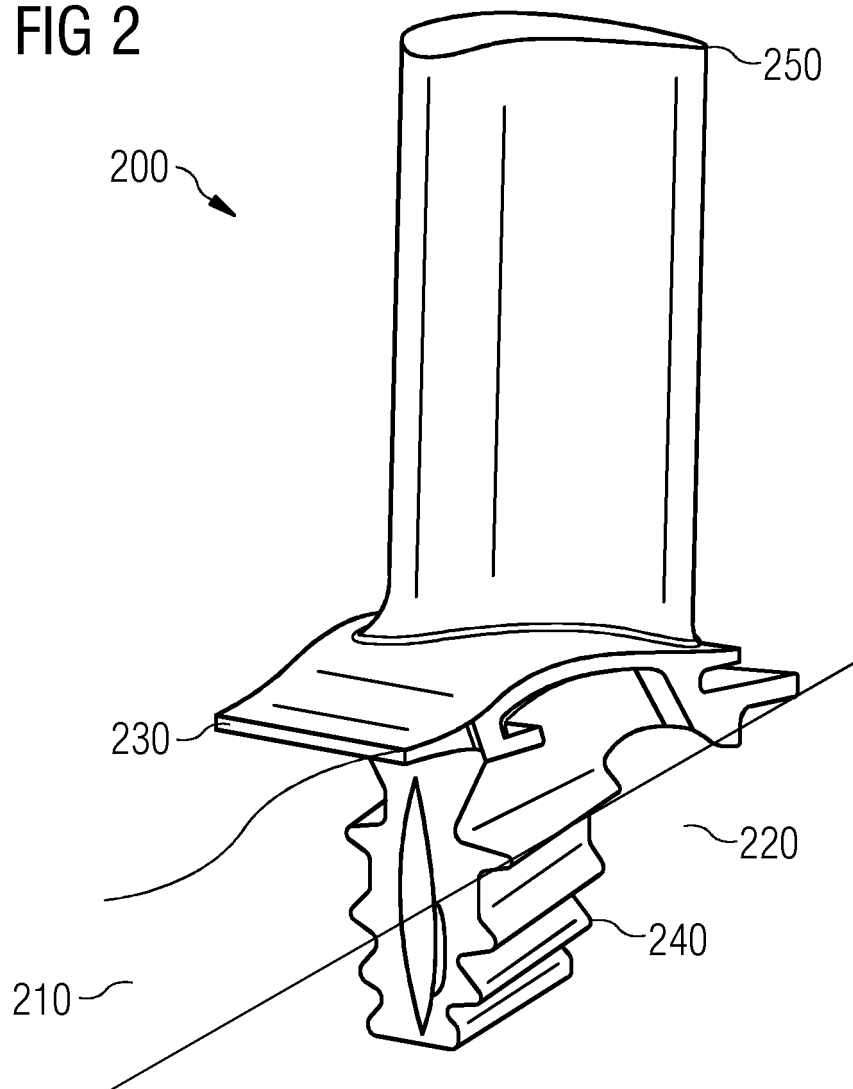
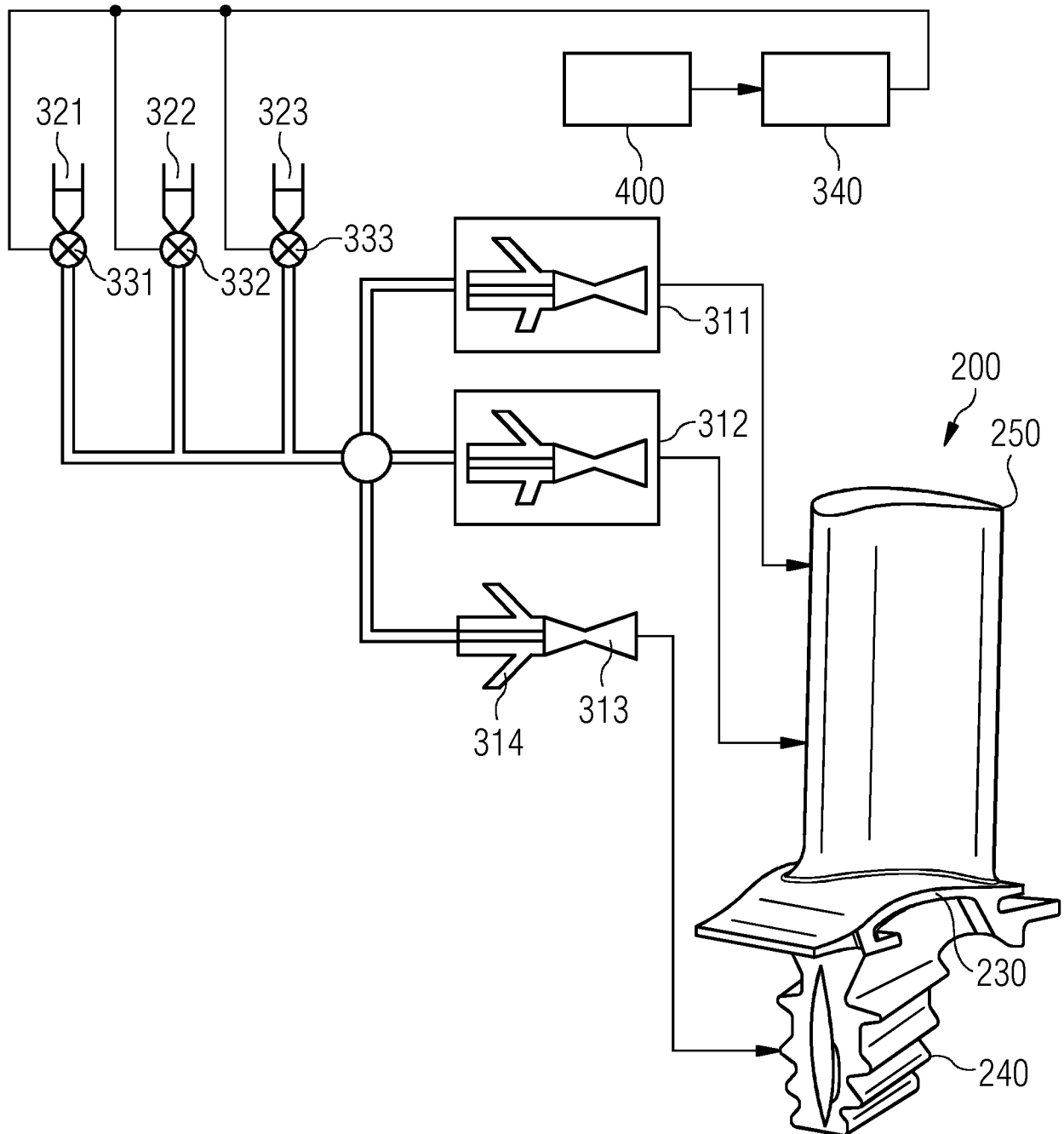


FIG 3





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