A method of Fluoride Ion Cleaning (FIC) of a component is provided. A FIC installation includes a reaction chamber and a reactive gas or a reactive gas mixture. A pressure of the reactive gas or the reactive gas mixture in the reaction chamber is set at least occasionally above atmospheric pressure, wherein the pressure in the reaction chamber is periodically lowered and raised.
FIG 5

FIG 6
Crack cleaning diagram:
Salt bath cleaning → Fluoride cleaning → Vacuum annealing

FIG 7
Diagrammatic FIC cleaning cycle:
FIC INSTALLATION AND METHOD FOR OPERATING A FIC INSTALLATION IN THE PRESSURE RANGE ABOVE ATMOSPHERIC PRESSURE

CROSS REFERENCE TO RELATED APPLICATIONS


FIELD OF INVENTION

[0002] The invention relates to an FIC installation and to a process for operating said FIC installation in the superatmospheric pressure range.

BACKGROUND OF INVENTION

[0003] Components of stationary gas turbines or aircraft turbines are reworked after use, it being necessary to remove oxides from cracks in these components so that the latter can be repaired. Here, use is made of the so-called FIC (Fluoride Ion Cleaning) process. In this process, the component is introduced into a reaction chamber into which the reactive gas, e.g. halogen gas, is then introduced, the oxide then reacting with the reactive gas, as a result of which the oxide is removed from the component.

SUMMARY OF INVENTION

[0004] An object of the invention is to specify an FIC installation and a process for operating an FIC installation which intensifies the chemical reaction and improves the cleaning action.

[0005] The object is achieved by an FIC installation and by a process as claimed in the independent claims. The dependent claims list further advantageous measures which can be combined with each other as desired to obtain further advantages.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1 shows an FIC installation.

[0007] FIGS. 2–5 show exemplary time profiles for the pressure within an FIC installation.

[0008] FIGS. 6, 7 schematically show the sequence of the cleaning process.

[0009] FIG. 8 shows a gas turbine.

[0010] FIG. 9 is a perspective view of a turbine blade or vane, and

[0011] FIG. 10 is a perspective view of a combustion chamber.

DETAILED DESCRIPTION OF INVENTION

[0012] FIG. 1 schematically shows an FIC installation 1. The FIC installation 1 comprises at least a reaction chamber 10 into which at least one component 4, 120, 130, 155 (FIGS. 8, 9, 10) can be introduced. The component 4, 120, 130, 155 has oxidation and/or corrosion products which are mainly present in cracks. The oxidation and corrosion products are also often present as a layer region. A reactive gas or reaction mixture, preferably a halide, preferably hydrogen fluoride (HF), can be introduced into the reaction chamber 10 via a valve 13 or pump 13, such that a reaction can take place therein between the reactive gas and the oxidation and/or corrosion product to be removed on the component 4, 120, 130, 155. According to the invention, the FIC installation is designed in such a manner that a pressure p which is greater than atmospheric pressure $p_{atm}$ (=1.01 bar at RT) can be set using means 13. Superatmospheric pressure range means at least a pressure which is greater than atmospheric pressure $p_{atm}$ in particular greater than 1.1 bar (=110 kPa).

[0013] The maximum superatmospheric pressure in the reaction chamber 10 is preferably 1.4 bar (140 kPa). Here, the reaction chamber 10 has seals as means 13 so that the reactive gas 7 in the superatmospheric pressure range cannot escape from the reaction chamber 10.

[0014] Alternatively or in addition, there is a valve 13 which controls the pressure in the reaction chamber 10, since the supply 7 with the reaction gas takes place at a superatmospheric pressure, i.e. a pressure vessel surface with the hydrogen fluoride (HF) used by way of example is at a superatmospheric pressure of greater than atmospheric pressure, in particular greater than 1.4 bar, such that the pressure in this pressure vessel has to be controlled.

[0015] As means, the device 1 preferably contains a pump 13 which is designed in such a manner that it can produce a superatmospheric pressure in the reaction chamber 10.

[0016] An exemplary time profile of the cleaning process, preferably using the FIC installation 1, is shown in the following table and in FIGS. 2 to 5:

<table>
<thead>
<tr>
<th>SEGMENT</th>
<th>Time</th>
<th>Pressure</th>
<th>HF</th>
<th>H₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEGMENT 1</td>
<td>t₁</td>
<td>PH</td>
<td>0</td>
<td>r₁</td>
</tr>
<tr>
<td>SEGMENT 2</td>
<td>t₂</td>
<td>PH</td>
<td>0</td>
<td>r₂</td>
</tr>
<tr>
<td>SEGMENT 3</td>
<td>t₃</td>
<td>PH</td>
<td>r₂</td>
<td>r₂</td>
</tr>
<tr>
<td>SEGMENT 4</td>
<td>t₄</td>
<td>PH</td>
<td>r₃</td>
<td>r₃</td>
</tr>
<tr>
<td>SEGMENT 5</td>
<td>t₅</td>
<td>PH</td>
<td>0</td>
<td>r₃</td>
</tr>
<tr>
<td>SEGMENT 6</td>
<td>t₆</td>
<td>PH</td>
<td>0</td>
<td>r₃</td>
</tr>
</tbody>
</table>

[0017] with the flow rates r₁, r₂, r₃, preferably r₃>r₂>r₁, and the pressures $P_{HF}$, in particular $P_{HF}$=1 atm, and the holding times t₁, t₂, t₃, preferably t₃>t₂>t₁. After the first segments 1, 2, the segments 4, 5 and 3 are repeated, and this represents a cycle.

[0018] FIG. 2 plots a time profile of the pressure $p$ in the reaction chamber 10. The initial pressure profile is not shown. At the start, this involves raising the temperature $T$ in the reaction chamber 10 up to a specific temperature, in particular above 1000 °C. After an initial phase, a pressure $p$ is preferably set to be at least occasionally greater than atmospheric pressure $p_{atm}$ and the pressure $p$ is kept constant for a holding time $t_p$. This represents a high-pressure phase ($P_{HP}$). The filling in the superatmospheric pressure range ($>p_{atm}$) means that more reactive gas from a reactive gas mixture penetrates into the cracks to be cleaned. This intensifies the chemical reaction and thus improves the cleaning action.

[0019] The gas in the reaction chamber 10 is preferably continuously pumped off in order to discharge consumed reaction products, and new gas (reactive gas, non-reactive gas) is added. This increases the productivity.

[0020] For a period of time $t_p$ in the high-pressure phase $P_{HP}$, the reaction chamber 10 is purged with a reactive gas 7 and preferably with a non-reactive gas. This represents a reactive gas mixture. The non-reactive gas may likewise represent a...
gas mixture which, however, does not react with the component. The period of time \( t_0 \), is preferably less than the holding time \( t_0 \) for \( P_{HR} \). The flow rate \( \mathbf{1} \) of the reactive gas or of the reactive gas mixture is preferably lower than the flow rate \( \mathbf{3} \) of the non-reactive gas, since the reaction chamber 10 is otherwise affected. During the purging time \((t_0-t)\) in the high-pressure phase, the flow rate of the non-reactive gas is preferably increased to \( \mathbf{3} \) \((\mathbf{3} \approx 2)\). This represents the crack-cleaning phase S4.

During the remaining holding time \((t_0-t)\) in the high-pressure phase, use is made only of a non-reactive gas (reactive gas flow rate \(=0 \)), preferably hydrogen (H\(_2\)). It is preferred if \((t_0-t) \approx 0\). This represents the crack-purging phase S5.

It is also possible to use a reactive gas or a mixture of reactive gas and non-reactive gas throughout the high-pressure phase, \((t_0-t) \approx 0\).

After the holding time \( t_0 \), the pressure \( p \) is lowered to a pressure \( P_{HR} \) lower than \( p_{atm} \) (low-pressure phase) and, after a specific holding time, is raised again to a pressure which is preferably greater than \( p_{atm} \) by introducing the reactive gas or the reactive gas mixture into the reaction chamber 10 by increasing the flow rate of the reactive gas or of the reactive gas mixture. The reactive gas mixture is produced by combining a reactive gas and a non-reactive gas. This represents the chamber-purging phase S3.

This process (S4, S5, S3) can be repeated periodically.

The process can also be carried out where \( P_{HR} \approx p_{atm} \) and \( P_{HR} \approx 2 \times p_{atm} \).

FIG. 3 shows a further time profile of the cleaning process. In contrast to FIG. 2, here the pressure \( p \) in the low-pressure phase \( P_{HR} \) is reduced to atmospheric pressure \( p_{atm} \) or preferably remains above atmospheric pressure \( p_{atm} \) (not shown).

In FIG. 4, as in FIGS. 2 and 3, the pressure \( p \) is periodically raised and lowered, i.e., held at a high-pressure phase \( P_{HR} \) and a low-pressure phase \( P_{HR} \), where, for a number of initial cycles, the pressure \( p \) in the high-pressure phase \( P_{HR} \) is restricted to atmospheric pressure \( p_{atm} \). Likewise, at the start of the process, the pressure \( p \) in the high-pressure phase \( P_{HR} \) may also be lower than atmospheric pressure \( p_{atm} \). After a certain amount of time, i.e., after a pair of high-pressure changes, the pressure \( p \) in the high-pressure phase is set to a pressure which is greater than \( p_{atm} \) and is preferably held at this pressure for a further length of time \( t_0 \). In the time which follows, the pressure, at which a pressure \( p \) which is greater than \( p_{atm} \) is used, can then continue to be held in the manner described in FIG. 2 or FIG. 3.

At the start of the cleaning process, in particular, the FIC cleaning can be carried out using a process according to the prior art, where pressures \( p_{atm} \) of between 200 mbar and less than atmospheric pressure are set and the pressure \( p \) is periodically lowered and raised again. The reaction proceeds very well at the start of the process, in particular, since sufficient reaction products which are easily accessible are freely accessible. However, in further steps of the cleaning process, it becomes more and more difficult to reach the remaining reaction products with the reactive gas, and therefore the installation is then operated in the superatmospheric pressure range.

FIG. 5 shows a further time profile of the cleaning process. Here, the pressure \( p \) in the high-pressure phase \( P_{HR} \) is periodically varied between a pressure \( p \) which is greater than atmospheric pressure \( p_{atm} \), and a pressure which is equal to or less than/equal to atmospheric pressure \( p_{atm} \). In FIG. 5, a pressure in the high-pressure phase \( P_{HR} \) is firstly set to be greater than \( p_{atm} \), a pressure in the high-pressure phase \( P_{HR} \) which is equal to \( p_{atm} \) then following; this is repeated. Of course, it is also possible to start with a pressure in the high-pressure phase of \( p_{HR} \) or for a pressure in the high-pressure phase which is greater than \( p_{atm} \) to then follow. The number of repetitions where \( p_{HR} \) or \( p_{HR} \) can be varied as desired.

At the start of the process, the temperature is raised to a specific temperature, in particular \( >1000^\circ \text{C} \). The temperature is preferably kept constant or controlled throughout the process, since it is possible that minimal temperature fluctuations may occur as a result of flooding with gas, with a change in the flow rate.

The reaction chamber is preferably continuously purged, preferably with hydrogen (H\(_2\)) or a non-reactive gas.

FIG. 6 schematically shows a process according to the invention for cleaning components which have oxide-contaminated cracks.

The process is suitable, in particular, for cleaning the rotor blades and guide vanes 120, 130 of a gas turbine 100 and other components which are subjected to high levels of loading during operation, for example the heat shield elements 150 of a combustion chamber 110 of the gas turbine 100. The process comprises the three steps of precleaning, fluoride ion cleaning and vacuum annealing. The precleaning, which is optional but not absolutely necessary and can consist, for example, in salt bath cleaning, serves to remove superficial oxides and other corrosion products from the surface of the component 120, 130, 155 to be cleaned, or to damage these oxides and corrosion products in such a way that the fluoride ion cleaning which follows can take place more effectively.

After the pretreatment, the component 120, 130, 155 is subjected to fluoride ion cleaning (FIC). During this FIC cleaning, which is already known per se, the component to be cleaned is exposed, in a cleaning chamber, to a cleaning gas atmosphere at temperatures in the region of \( 1000^\circ \text{C} \). The cleaning gas contains a hydrogen halide in the form of hydrogen fluoride (HF), which dissociates at the temperatures which prevail to form fluoride ions which, in turn, are suitable for removing even complex oxides which have formed in the cracks in the component, with metal fluorides being formed.

In the process, use is preferably made of a cleaning gas which contains 18% by volume to 30% by volume of hydrogen fluoride or hydrogen fluoride, the remaining gas being a non-oxidizing and non-corrosive gas and, in particular, a gas such as a hydrogen gas which has a reducing action on oxides. During the FIC cleaning, the temperature in the cleaning chamber is in a range from \( 980^\circ \text{C} \) to \( 1100^\circ \text{C} \), in particular to \( 1020^\circ \text{C} \).

The cleaning gas in the form of the HF/H\(_2\) mixture is impinged on the component 120, 130, 155 to be cleaned in a plurality of cleaning cycles which are interrupted by purging cycles using a non-oxidizing purging gas which, in particular, has a reducing action, for example hydrogen (H\(_2\)). The purging cycles can be assisted by draining the cleaning chamber, it then being necessary to refill the cleaning chamber with the cleaning gas before the next cleaning cycle. The cleaning can also be interrupted by pumping off the cleaning gas. The exemplary embodiment shown employs four cleaning cycles which are interrupted by a total of three purging cycles, purging also taking place at the end of the last cleaning cycle.
However, the number of cleaning and purging cycles may also be considerably higher. It is preferred to carry out three to ten purging cycles.

[0037] The cleaning cycles, over the course of which the cleaning gas is impinged on the component, each last for 10 to 60 minutes, in particular 45 minutes, it being possible for the cleaning cycles to last for the same amount of time. The first and the fourth cleaning cycles can also last slightly longer than the two middle cleaning cycles. However, this is because the temperature first has to be increased to the desired range in the first cycle, and the temperature has to be lowered again in the last cycle. It is preferred to carry out five cleaning cycles.

[0038] The last cycle of the FIC cleaning is followed by solution annealing treatment during which reaction products, for example γ’ phases as occur in the case of nickel-based superalloys, are removed.

[0039] FIG. 7 shows an exemplary temperature profile T and a pressure profile p in a graph plotted against time t. A component 120, 130, 155 to be cleaned is introduced into the cleaning chamber, and the temperature T is increased to the desired range. In the process, the reactive gas 7, here an HF/H₂ mixture, is fed into the cleaning chamber 10. In this exemplary embodiment, four cleaning cycles take place and these are interrupted by three purging cycles. In these purging cycles, the gas mixture is also pumped off, and therefore the pressure within the chamber is reduced considerably during the purging cycles. In addition, a gas with a reducing action, for example hydrogen, is fed into the chamber.

[0040] As already mentioned in the introduction, the process according to the invention is suitable, in particular, for cleaning gas turbine components which consist of alloys having a chromium content of at least 10% by weight.

[0041] FIG. 8 shows, by way of example, a partial longitudinal section through a gas turbine 100. In the interior of the gas turbine 100 has a rotor 103 with a shaft 101 is mounted such that it can rotate about an axis of rotation 102 and is also referred to as the turbine rotor. An intake housing 104, a compressor 105, a, for example, toroidal combustion chamber 110, in particular an annular combustion chamber, with a plurality of coaxially arranged burners 107, a turbine 108 and the exhaust-gas housing 109 follow one another along the rotor 103. The annular combustion chamber 110 is in communication with a, for example, annular hot-gas passage 111, where, by way of example, four successive turbine stages 112 form the turbine 108. Each turbine stage 112 is formed, for example, from two blade or vane rings. As seen in the direction of flow of a working medium 113, in the hot-gas passage 111 a row of guide vanes 115 is followed by a row 125 formed from rotor blades 120.

[0042] The guide vanes 130 are secured to an inner housing 138 of a stator 143, whereas the rotor blades 120 of a row 125 are fitted to the rotor 103 for example by means of a turbine disk 133. A generator (not shown) is coupled to the rotor 103.

[0043] While the gas turbine 100 is operating, the compressor 105 sucks in air 135 through the intake housing 104 and compresses it. The compressed air provided at the turbine-side end of the compressor 105 is passed to the burners 107, where it is mixed with a fuel. The mix is then burnt in the combustion chamber 110, forming the working medium 113. From there, the working medium 113 flows along the hot-gas passage 111 past the guide vanes 130 and the rotor blades 120. The working medium 113 is expanded at the rotor blades 120, transferring its momentum, so that the rotor blades 120 drive the rotor 103 and the latter in turn drives the generator coupled to it.

[0044] While the gas turbine 100 is operating, the components which are exposed to the hot works working medium 113 are subject to thermal stresses. The guide vanes 130 and rotor blades 120 of the first turbine stage 112, as seen in the direction of flow of the working medium 113, together with the heat shield elements which line the annular combustion chamber 110, are subject to the highest thermal stresses. To be able to withstand the temperatures which prevail there, they may be cooled by means of a coolant. Substrates of the components may likewise have a directional structure, i.e. they are in single-crystal form (SX structure) or have only longitudinally oriented grains (DS structure). By way of example, iron-based, nickel-based or cobalt-based superalloys are used as material for the components, in particular for the turbine blade or vane 120, 130 and components of the combustion chamber 110. Superalloys of this type are known, for example, from EP 1 204 776 B1, EP 1 310 454, EP 1 319 729 A1, WO 99/67435 or WO 00/44949.

[0045] The blades or vanes 120, 130 may likewise have coatings protecting against corrosion (MCrAlX, M is at least one element selected from the group consisting of iron (Fe), cobalt (Co), nickel (Ni), X is an active element and stands for yttrium (Y) and/or silicon, scandium (Sc) and/or at least one rare earth element, or hafnium). Alloys of this type are known from EP 0 486 489 B1, EP 0 786 017 B1, EP 0 412 397 B1 or EP 1 306 454 A1.

[0046] It is also possible for a thermal barrier coating, which consists for example of ZrO₂.Y₂O₃—ZrO₂, i.e. unstabilized, partially stabilized or fully stabilized by yttrium oxide and/or calcium oxide and/or magnesium oxide, to be present on the MCrAlX. Columnar grains are produced in the thermal barrier coating by suitable coating processes, such as for example electron beam physical vapor deposition (EB-PVD).

[0047] The guide vane 130 has a guide vane root (not shown here), which faces the inner housing 138 of the turbine 108, and a guide vane head which is at the opposite end from the guide vane root. The guide vane head faces the rotor 103 and is fixed to a securing ring 140 of the stator 143.

[0048] FIG. 9 shows a perspective view of a rotor blade 120 or guide vane 130 of a turbomachine, which extends along a longitudinal axis 121.

[0049] The turbomachine may be a gas turbine of an aircraft or of a power plant for generating electricity, a steam turbine or a compressor.

[0050] The blade or vane 120, 130 has, in succession along the longitudinal axis 121, a securing region 400, an adjoining blade or vane platform 403 and a main blade or vane part 406 and a blade or vane tip 415. As a guide vane 130, the vane 130 may have a further platform (not shown) at its vane tip 415.

[0051] A blade or vane root 183, which is used to secure the rotor blades 120, 130 to a shaft or a disk (not shown), is formed in the securing region 400. The blade or vane root 183 is designed, for example, in hammerhead form. Other configurations, such as a fin-tree or dovetail root, are possible. The blade or vane 120, 130 has a leading edge 409 and a trailing edge 412 for a medium which flows past the main blade or vane part 406.

[0052] In the case of conventional blades or vanes 120, 130, by way of example solid metallic materials, in particular superalloys, are used in all regions 400, 403, 406 of the blade.
or vane 120, 130. Superalloys of this type are known, for example, from EP 1 204 776 B1, EP 1 306 454, EP 1 319 729 A1, WO 99/67435 or WO 00/44949. The blade or vane 120, 130 may in this case be produced by a casting process, by means of directional solidification, by a forging process, by a milling process or combinations thereof.

[0053] Workpieces with a single-crystal structure or structures are used as components for machines which, in operation, are exposed to high mechanical, thermal and/or chemical stresses. Single-crystal workpieces of this type are produced, for example, by directional solidification from the melt. This involves casting processes in which the liquid metallic alloy solidifies to form the single-crystal structure, i.e. the single-crystal workpiece, or solidifies directionally. In this case, dendritic crystals are oriented along the direction of heat flow and form either a columnar crystalline grain structure (i.e. grains which run over the entire length of the workpiece and are referred to here, in accordance with the language customarily used, as directionally solidified) or a single-crystal structure, i.e. the entire workpiece consists of one single crystal. In these processes, a transition to globular (polycrystalline) solidification needs to be avoided, since non-directional growth inevitably forms transverse and longitudinal grain boundaries, which negate the favorable properties of the directionally solidified or single-crystal component. Where the text refers in general terms to directionally solidified microstructures, this is to be understood as meaning both single crystals, which do not have any grain boundaries or at most have small-angle grain boundaries, and columnar crystal structures, which do have grain boundaries running in the longitudinal direction but do not have any transverse grain boundaries. This second form of crystalline structures is also described as directionally solidified microstructures (directionally solidified structures). Processes of this type are known from U.S. Pat. No. 6,024,792 and EP 0 892 090 A1.

[0054] The blades or vanes 120, 130 may likewise have coatings protecting against corrosion or oxidation e.g. (MCrAIx; M is at least one element selected from the group consisting of iron (Fe), cobalt (Co), nickel (Ni), X is an active element and stands for yttrium (Y) and/or silicon and/or at least one rare earth element, or hafnium (Hf)). Alloys of this type are known from EP 0 486 489 B1, EP 0 786 017 B1, EP 0 412 397 B1 or EP 1 306 454 A1. The density is preferably 95% of the theoretical density. A protective aluminum oxide layer (TiO2-thermally grown oxide layer) is formed on the MCrAIx layer (as an intermediate layer or as the outermost layer).

[0055] The layer preferably has a composition Co-30Ni-28Cr-8Al-0.6Y-0.7Si or Co-28Ni-24Cr-10Al-0.6Y. In addition to these cobalt-based protective coatings, it is also preferable to use nickel-based protective layers, such as Ni-10Cr-12Al-0.6Y-3Re or Ni-12Co-21Cr-11Al-0.4Y-2Re or Ni-25Co-17Cr-10Al-0.4Y-1.5Re.

[0056] It is also possible for a thermal barrier coating, which is preferably the outermost layer and consists for example of ZrO2-Y2O3-ZrO2, i.e. unstabilized, partially stabilized or fully stabilized by yttrium oxide and/or calcium oxide and/or magnesium oxide, to be present on the MCrAIx. The thermal barrier coating covers the entire MCrAIx layer. Columnar grains are produced in the thermal barrier coating by suitable coating processes, such as for example electron beam physical vapor deposition (EB-PVD).

[0057] Other coating processes are possible, for example atmospheric plasma spraying (APS), LPPS, VPS or CVD. The thermal barrier coating may include grains that are porous or have micro-cracks or macro-cracks, in order to improve the resistance to thermal shocks. The thermal barrier coating is therefore preferably more porous than the MCrAIx layer.

[0058] Refurbishment means that after they have been used, protective layers may have to be removed from components 120, 130 (e.g. by sand-blasting). Then, the corrosion and/or oxidation layers and products are removed. If appropriate, cracks in the component 120, 130 are also repaired. This is followed by recoating of the component 120, 130, after which the component 120, 130 can be reused.

[0059] The blade or vane 120, 130 may be hollow or solid in form. If the blade or vane 120, 130 is to be cooled, it is hollow and may also have film-cooling holes 418 (indicated by dashed lines).

[0060] FIG. 10 shows a combustion chamber 110 of a gas turbine. The combustion chamber 110 is configured, for example, as what is known as an annular combustion chamber, in which a multiplicity of burners 197, which generate flames 156, arranged circumferentially around an axis of rotation 102 open out into a common combustion chamber space 154. For this purpose, the combustion chamber 110 overall is of annular configuration positioned around the axis of rotation 102.

[0061] To achieve a relatively high efficiency, the combustion chamber 110 is designed for a relatively high temperature of the working medium M of approximately 1000° C. to 1600° C. To allow a relatively long service life even with these operating parameters, which are unfavorable for the materials, the combustion chamber wall 153 is provided, on its side which faces the working medium M, with an inner lining formed from heat shield elements 155. On the working medium side, each heat shield element 155 made from an alloy is equipped with a particularly heat-resistant protective layer (MCrAIx layer and/or ceramic coating) or is made from material that is able to withstand high temperatures (solid ceramic bricks). These protective layers may be similar to the turbine blades or vanes, i.e. for example MCrAlX. M is at least one element selected from the group consisting of iron (Fe), cobalt (Co), nickel (Ni), X is an active element and stands for yttrium (Y) and/or silicon and/or at least one rare earth element or hafnium (Hf). Alloys of this type are known from EP 0 486 489 B1, EP 0 786 017 B1, EP 0 412 397 B1 or EP 1 306 454 A1.

[0062] It is also possible for a, for example, ceramic thermal barrier coating to be present on the MCrAIx, consisting for example of ZrO2-Y2O3-ZrO2, i.e. unstabilized, partially stabilized or fully stabilized by yttrium oxide and/or calcium oxide and/or magnesium oxide. Columnar grains are produced in the thermal barrier coating by suitable coating processes, such as for example electron beam physical vapor deposition (EB-PVD).

[0063] Other coating processes are possible, e.g. atmospheric plasma spraying (APS), LPPS, VPS or CVD. The thermal barrier coating may include grains that are porous or have micro-cracks or macro-cracks, in order to improve the resistance to thermal shocks.

[0064] Refurbishment means that after they have been used, protective layers may have to be removed from heat shield elements 155 (e.g. by sand-blasting). Then, the corrosion and/or oxidation layers and products are removed. If appropriate, cracks in the heat shield element 155 are also
repaired. This is followed by recoating of the heat shield elements 155, after which the heat shield elements 155 can be reused.

Moreover, a cooling system may be provided for the heat shield elements 155 and/or their holding elements, on account of the high temperatures in the interior of the combustion chamber 110. The heat shield elements 155 are then, for example, hollow and may also have cooling holes (not shown) opening out into the combustion chamber space 154.

36. A process for Fluoride Ion Cleaning (FIC) of a component, comprising:
   providing a FIC installation with a reaction chamber and a reactive gas or a reactive gas mixture;
   setting a pressure of the reactive gas or the reactive gas mixture in the reaction chamber at least occasionally above atmospheric pressure; and periodically lowering and raising the pressure in the reaction chamber.

37. The process as claimed in claim 36, wherein the pressure in the reaction chamber is at least occasionally between atmospheric pressure and 1.4 bar (140 kPa).

38. The process as claimed in claim 36, wherein the pressure in the reaction chamber is occasionally constant, the constant pressure time being between 4 min and 10 min.

39. The process as claimed in claim 36, wherein the pressure in the reaction chamber is occasionally below atmospheric pressure, the pressure below atmospheric pressure lasting between 5 min and 10 min.

40. The process as claimed in claim 36, wherein the pressure in the reaction chamber is above atmospheric pressure for 25 min to 65 min.

41. The process as claimed in claim 36, wherein a high-pressure phase comprises a higher pressure than a low-pressure phase, and wherein during the high-pressure phase the reaction chamber is purged with the reactive gas or the reactive gas mixture representing a crack-cleaning phase.

42. The process as claimed in claim 36, wherein during the high-pressure phase the component is purged only with a non-reactive gas representing a crack-purging phase.

43. The process as claimed in claim 42, wherein a flow rate of the non-reactive gas is reduced during the high-pressure phase between two values, when a flow rate of the reactive gas mixture or of the reactive gas is above zero (>0).

44. The process as claimed in claim 41, wherein the pressure below atmospheric pressure is lowered to a low-pressure phase, wherein purging is carried out only with a non-reactive gas representing a chamber-purging phase.

45. The process as claimed in claim 41, wherein one crack-cleaning phase lasts 45 min.

46. The process as claimed in claim 44, wherein the chamber-purging phase lasts 5 min.

47. The process as claimed in claim 36, wherein the reaction chamber is drained during various phases.

48. The process as claimed in claim 42, wherein the non-reactive gas comprises hydrogen.

49. The process as claimed in claim 36, further comprising: annealing the component in a vacuum after a cleaning treatment in the reaction chamber, wherein the annealing is carried out at the γ'-solution annealing temperature of a material used for the component, and wherein the annealing lasts for at least two hours.

50. The process as claimed in claim 36, wherein a temperature is kept constant in the reaction chamber except during heating at the start of the process and cooling at the end of the process.

51. The process as claimed in claim 36, wherein the reaction chamber is continuously purged with hydrogen, and wherein the reaction chamber is continuously drained.

52. The process as claimed in claim 36, wherein the reactive gas mixture comprises from 18% by volume to 30% by volume a hydrogen halide.

53. The process as claimed in claim 36, wherein the reactive gas mixture or the reactive gas is impinged on the cracks in the component at a temperature of 980 °C. to 1100 °C.

54. The process as claimed in claim 36, further comprising: precleaning the component in a salt bath.

55. The process as claimed in claim 36, wherein, after using the reactive gas mixture, a reducing gas is used at the end of the high-pressure phase.

* * * * *