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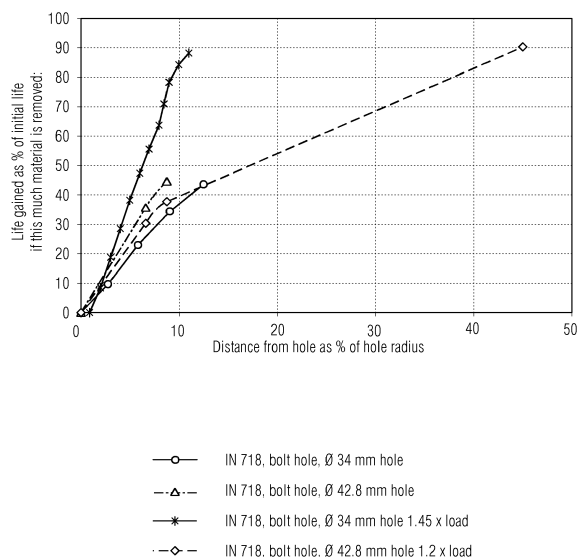
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(54) **METHODS FOR OPERATING AND TREATING A TURBINE ASSEMBLY**

(57) The present invention relates to two methods for operating and treating a turbine assembly. The first method comprises at least the steps of: determining at least a section (12) of the turbine assembly (10) that is prone to fatigue while operating the turbine assembly (10), defining a specific operating time of the section (12) of the turbine assembly (10), operating the section (12) up to the specific operating time, treating the section (12) that is prone to fatigue after operating the section (12) up to the specific operating time by material removal and thus expose a sub-section (14) of the section (12) and operating the sub-section (14). The second method comprises at least the steps of: determining at least a section (12a) of the turbine assembly (10a) that is prone to fatigue while operating the turbine assembly (10a), overlaying the section (12a) with an additional depth of material to form an additional layer (24) of material, defining a specific operating time of the layered section (12a), operating the turbine assembly (10a) up to the specific operating time, treating the layered section (12a) by material removal from the additional layer (24) of material and operating the section (12a).

Due to these methods a cyclic life of the turbine assembly (10, 10a) can be advantageously extended.

FIG 10



Description

Field of the Invention

5 **[0001]** The present invention relates to two methods for operating and treating a turbine assembly.

Background to the Invention

10 **[0002]** Modern turbines often operate at extremely high temperatures and are operated with high speed. This causes high stresses that act on turbine components and may have detrimental effects on selected parts or sections of the components especially prone to fatigue. For example, the effect of temperature on the turbine blades and/or stator vanes can be detrimental to the efficient operation of the turbine and can, in extreme circumstances, lead to distortion and possible failure of the blade or vane. Hence, turbines may include hollow blades or vanes incorporating cooling channels, inserts and pedestals for cooling purposes to overcome this risk of failure. However, cooling holes, especially at the disc of a turbine assembly that feed cooling medium to the aerofoil, are regions that are exposed to high stress and are prone to cyclic life limiting features. Moreover, structures connecting turbine assemblies, like turbine blades or vanes, with a casing or with another components, e.g. a disc or platform, tend to show fatigue, especially in regions of fastening structures, like, for example, bolt holes.

15 **[0003]** Many turbine components exhibit a shorter than optimal operating life due to failure mechanisms such as Low Cycle Fatigue (LCF). Hitherto the cyclic life of the component is established analytically or via mechanical testing on bespoke test rigs. Depending on the component material chemistry and metallurgical structure the design intent may be either to remove the component from service prior to the onset of crack initiation or to allow crack initiation and to predict crack growth through fracture mechanics methods. It is normal and prudent practice for the Turbomachinery operator to maintain a numerical count of operating cycles the machine and/or components has endured. It is possible to modify the count with a multiplication factor to compensate for more damaging operating regimes such as rapid starts to full power. Once the declared cyclic life has been reached it is normal to declare the component unfit for further service and the component is sentenced as scrap and sent for recycling. With these approaches it can occur that components are discarded that may still have operating capacity thus wasting resources and money.

20 **[0004]** It is a first objective of the invention to provide a method for operating and treating a turbine assembly with which the above-mentioned shortcomings can be mitigated, and especially, with which the benefit of environmental, energy and cost savings can be provided. Moreover, turbine assemblies with longer cyclic life in comparison to turbine assemblies operated and treated according to state of the art principles can be obtained.

25 **[0005]** It is a second objective of the present invention to provide an alternative method for operating and treating a turbine assembly that results in the same advantages as stated above.

30
35 Summary of the Invention

[0006] Accordingly, the present invention provides a method for operating and treating a turbine assembly, wherein the method comprises at least the steps of: determining at least a section of the turbine assembly that is prone to fatigue while operating the turbine assembly, defining a specific operating time of the section of the turbine assembly, operating the section up to the specific operating time, treating the section that is prone to fatigue, especially low cycle fatigue, after operating the section up to the specific operating time by material removal and thus expose a sub-section of the section and operating the sub-section.

40 **[0007]** Due to the inventive matter an advantageous repair or refurbishment strategy can be provided. It allows a rejuvenation of the section and thus the whole turbine assembly by material removal of the affected areas of the turbine assembly. Typically, only small aspects of the turbine assembly reach its cycle life; the remaining features in the turbine assembly are often capable of many more cycles. This solution gives an effective and economical method of salvaging components that have reached the end of their initial cyclic life allowing them to be returned to engine service resulting in significant cost savings to overhauled assemblies and supply chain. There is a substantial environmental and energy saving benefit in not scrapping the turbine assembly which necessitates re-melting, re-forging and re-machining which also carries the attendant risk of being sentenced as scrap at any point of the process for reasons such as material defect, incorrect dimensions during machining or handling damage. The re-machining cost of the section and associated non-destructive testing is minimal compared to the cost of the production of the turbine assembly or parts thereof, like a disc forging, disc machining, curvic or hirth teeth and formation of blade roots. Moreover, by treating the section further operating time of the sub-section of the section can be gained.

50 **[0008]** Even if a term like section, material, sub-section, rim, layer or surface (also see below) is used in the singular or in a specific numeral form in the claims and the specification the scope of the patent (application) should not be restricted to the singular or the specific numeral form. It should also lie in the scope of the invention to have more than

one or a plurality of the above mentioned structure(s).

[0009] A turbine assembly is intended to mean an assembly provided for a turbine, like a gas turbine, wherein the assembly for example possesses or is at least a disc, a platform or an aerofoil. Preferably, the turbine assembly is part of a turbine cascade and/or turbine wheel comprising circumferential arranged aerofoils.

[0010] Moreover, it may further comprise an outer and an inner platform arranged at opponent ends of the aerofoil(s) or a shroud and a root portion arranged at opponent ends of the aerofoil(s). A "section of the turbine assembly that is prone to fatigue while operating the turbine assembly" may be any structure or region of the turbine assembly feasible for a person skilled in the art that shows fatigue while operated or under selected operating conditions or after a specific operating time. This vulnerability of the section to fatigue may be caused due to a specific geometry of the section or its surroundings, a selected positioning at the turbine assembly e.g. relatively to negatively influencing factors, like a flow path of hot flow medium, or a specific function of the section, like a fastening function.

[0011] The term "specific operating time" should be understood as the time the turbine assembly is operated until a pre-defined number of operating cycles are performed and thus a certain degree of accumulated damage of the section caused by fatigue is to be expected. Further, the specific operating time is the time the turbine assembly will be operated beforehand of the (respective) refurbishment step. The specific operating time is less than the maximum operating time of the turbine assembly, wherein the maximum operating time is the time until the turbine assembly or a part thereof is damaged to such a degree that it is unsafe or unfit to further operate it. The specific operating time may also be referred to as pre-defined fatigue life and the maximum operating time as nominal fatigue life.

[0012] The removal of material can be performed by any method feasible for a person skilled in the art, like drilling, milling or machining away. It is, for example, possible to use either machine tools and/or hand dressing techniques with or without the use of guide fixtures. Furthermore, the material is removed from a nominal surface of the section exposing a surface of the sub-section. In this context nominal surface should be understood as the surface of the section as it is embodied at a start of a service life of the turbine assembly. Further, a sub-section should be understood as a part of the section e.g. being spatially positioned "beneath" the nominal surface of the section.

[0013] It is further provided that the section is a section comprising a change in its contour. Hence, an especially vulnerable embodied structure can be treated and refurbished. The feature changing the contour may be any feature feasible for a person skilled in the art, like an edge, a pedestal, a step, a counter bore or a hole. Preferably, the section comprises a stress raiser or the feature causing the change in contour is a stress raiser. In other words, the feature increases a stress concentration in the section, wherein the stress is at the highest at the location of the feature or adjacent to the feature.

[0014] Moreover, the section is preferably a hole with its surface or rim. Thus, a structure widely used in Turbomachinery can be effectively rejuvenated. In this exemplary embodiment the hole is the stress raiser, which increases the stress at the surface or rim of the hole. Hence, the material to be removed is the material surrounding the hole or stress raiser.

[0015] Furthermore, the section is preferably a hole, e.g. a cooling hole that has a breakout that breaks out at its surface or rim at an angle building an acute corner, wherein the acute corner is the life limiting area or feature. Further, the material of the acute corner would be removed (e.g. by drilling, milling or be machined away) for example perpendicular to a surface of the corner or at an angle to the surface.

[0016] Beneficially, the hole is a cooling hole or a bolt hole. Due to this, regions being subjected to e.g. high connecting forces or high temperatures as well as to periodically changes in temperature can be refurbished. The hole can be any cooling hole or bolt hole feasible for a person skilled in the art, like an exit or entry hole for cooling medium of an aerofoil or its root portion or of the aerofoil itself or a fastening hole of e.g. the aerofoil or the disc. Preferably, the hole is a hole of a turbine disc. The section that is prone to fatigue may be in these exemplary embodiments the region at an acute corner of a cooling air feed hole at a bottom of a blade root slot, a region around a bolt hole of a multi tie bolted rotor arrangement, a region around an air transfer hole or a region around a bolt clearance hole.

[0017] Often the site of the cyclically aged material is localized at the feature changing the contour of the section e.g. a hole and penetrates the sections structural material surrounding the feature.

[0018] According to an advantageous embodiment of the invention the method comprises the further step of: treating the section by material removal by enlarging a diameter of the hole. Hence, material exposed to a high stress and being compromised during beforehand operation of the turbine assembly is removed rejuvenating the hole. The amount of material removed would vary from part to part and from service strategy to service strategy. The amount of material to be removed should result in a balance between an optimal life recovery for as few services as possible (or within acceptable/scheduled levels of servicing) and acceptable levels of material removal without compromising the overall integrity of the component. This amount could have any value between 1% and 60% of an original diameter of the hole feasible for a person skilled in the art.

[0019] According to a preferred embodiment of the invention the method comprises the further or alternative step of: treating the section by material removal from an acute corner of a hole with a breakout that breaks out at a surface of the hole at an angle. Hence, a life limiting area can advantageously be removed.

[0020] However, it was found, that by removing about 10% to 30% of the diameter of the hole or about 10% to 30%

of a diameter of the hole with the breakout at the acute corner an advantageous refurbishment could be obtained. The proposed range has been shown to have a satisfactory balance between a gain in cycle lives and a prevention of negative effects on the overall integrity of the turbine assembly or its treated section. The component refurbishment technique can rejuvenate the component fully or partly dependent on the amount of material removed. Hence, it is possible to restart the cyclic "clock" by fully removing all the aged material or partially "wind the cyclic clock back" by removing a lesser amount of material if say another feature that could not be reworked i.e. the blade root was the next feature to exhaust its cyclic life.

[0021] In case of the embodiment with the hole that breaks out at its surface at an angle or that comprises the angled breakout the removal can be performed easily when the acute corner is removed e.g. drilled/machined away.

[0022] Further, the geometry of the feature (hole) or the geometry around the feature such as the hole break out angle affects or impacts the stress concentration in the material at the feature or of the material surrounding the feature in different (radial) distances from the feature or from a midpoint of the hole. Hence, the amount of material removed is, for example, dependent of the geometry of the feature. Thus, also a function of the hole can affect the amount of material to be removed. For example, at the surface or rim of a cooling hole that, for example, breaks out at an angle the stress concentration factor for the material is high and drops quickly with increasing distance from the surface or rim of the hole. In contrast, at a surface or rim of a bolt hole the stress concentration factor is normally lower. However, the decline of the stress concentration factor is normally shallower in comparison with a cooling hole. Consequently, to gain the same amount of cycle lives the removal of material may have to be higher for a bolt hole in comparison with a cooling hole. Thus, it may be enough to remove 10% to 25% of the original diameter of the hole for a hole with a diameter up to 16 mm, mostly cooling holes, and 10% to 30% of the original diameter of a hole with a diameter above 16 mm, normally bolt holes. For a cooling hole with a diameter of 5.6 millimeter (mm) it might be enough to remove 0.7 mm (12.5%) and for a bolt hole with a diameter of 42.8 mm, for example, 10.7 mm (25%) may have to be removed in order to sufficiently rejuvenate the cyclic life.

[0023] Furthermore, other factors influence the amount of material that requires removal. Such a factor may be any one feasible for a person skilled in the art, for example, a characteristic of the section or turbine assembly (like material, material composition, size) or an operating condition of the turbine engine (like temperature, temperature change, speed, flow velocity of a working or cooling fluid). To determine these factors empirical values, like in-service life experience or cycle life testing, can be included into the consideration. Hence, the method comprises the further step of: determining the amount of material to be removed by a consideration of at least one of the factors consisting out of the group of: internal stress, contact stress, surface stress, temperature, material capability, material thickness, operating speed, flow velocity of a flow medium and desired future fatigue life.

[0024] The consideration can be done by any method feasible for a person skilled in the art, like empirically or statistically. Beneficially, the method comprises the further step of: determining the amount of material to be removed or an extent of the aged or degraded material by at least one of the methods out of the group consisting of: Finite Element Analysis, hand calculations, obtaining results from laboratory testing or from examination of engine run components and/or applying statistics over the results. Hence, results can be obtained easily. For example, during the procedures "laboratory testing" or "examination of engine run components" components are cut-up (or sectioned) and the material is tested or examined.

[0025] Preferably, the method comprises the further step of: determining the specific operating time by a use of a cumulative damage technique. Thus, proven concepts can be employed. This may be any technique feasible for a person skilled in the art, like the linear damage rule, the Marko-Starky theory, damage theories based on endurance limit reduction, the Corton-Dolon model, the Freudenthal-Heller approach, two-stage linear damage theories, damage theories based on crack growth concept, the damage curve approach, the double-damage curve approach, the hybrid theory or the Palmgren-Miner rule.

[0026] In a further realisation of the invention the method comprises the further step of: determining the specific operating time by a use of the Palmgren-Miner rule. By considering the amount of material that would be compromised at different material depth away from the feature (e.g. a hole) during a maximal operating time the specific operating time can be determined easily. Moreover, the further operating time of the sub-section can be also determined.

[0027] According to a further aspect of the invention the material removal from the section is performed in one single step. Hence, the risk of damaging the turbine assembly or the section during the refurbishment is minimised. Alternatively, the material removal from the section can be performed in several steps. This provides the possibility to perform a security check of the section before each subsequent refurbishment step.

[0028] Ideally, the refurbishment would be done such that the cyclic live recovered was high and the times this would need was minimal, and also that an acceptable amount of material was removed each time without compromising the turbine assembly or the section thereof. In general, the more material removed, the more life will be recovered. However, for further refurbishment cycles the rate reduces.

[0029] The number of reworking opportunities depends on how much structural material remains after reworking to carry out the required component duty. This limited material removal effectively moves back the LCF count closer to

original design life allowing the turbine assembly to be returned to service with a revised life limiting declaration or only sufficient material to be removed to meet a pre-determined cyclic life. Thus, the method comprises the further step of: repeating the steps of defining the specific operating time, operating the section, treating the section and operating the sub-section several times. Hence, a cyclical rejuvenation can be performed.

[0030] With this invention it may be possible to use a singular turbine assembly, e.g. a disc, refurbished one or more times to achieve a full design life of the Turbomachinery. The refurbished component life cycle cost approximates to:

$$\begin{aligned} & ((1/\text{Number of rework cycles}) * \text{Initial component cost}) \\ & + (\text{Number of rework cycles} * \text{Rework cost}) \end{aligned}$$

[0031] The above formula is comparative to replacing Low Cycle Fatigue expired parts.

[0032] A number of the refurbishment steps may be planned beforehand of the first operating of the turbine assembly. In this case the specific operating time and each subsequent operating time are determined beforehand of the first operation by applying the Palmgren-Miner rule using a number of summands, wherein the number of summands is equal to the number of operating steps or the treatment/refurbishment steps is n-1, wherein n is the number of positions examined to determine possible operating cycles. It may be also possible to determine if a further refurbishment step is possible after the sub-section is operated its further operating time. This would be done by determining the further operating time after the beforehand operating time of the respective sub-section is finished.

[0033] In addition, the further step of: defining the specific operating time, operating the section, treating the section and operating the sub-section can be repeated until an abort criterion is reached. This abort criterion may be any criterion feasible for a person skilled in the art, like reaching a maximal operating time of the section, reaching a rework limit, like a minimal material condition of the section (e.g. thickness, instability) or an unsuitable geometry of the section.

[0034] A secure operation of the turbine assembly and thus the turbine engine can be provided when the further step of: defining a specific operating time, operating the section, treating the section and operating the sub-section are repeated till the defined specific operating time in the step defining the specific operating time is less than a difference between a maximum operating time of the section and the already performed operating time(s).

[0035] In a further advantageous embodiment turbine assembly is a turbine disc.

[0036] The present invention also provides a method for operating and treating a turbine assembly, that comprises at least the steps of: determining at least a section of the turbine assembly that is prone to fatigue while operating the turbine assembly, overlaying the section with an additional depth of material to form an additional layer of material, defining a specific operating time of the layered section, operating the turbine assembly up to the specific operating time, treating the layered section by material removal from the additional layer of material and operating the section.

[0037] Due to the inventive matter an advantageous repair or refurbishment strategy can be provided. It allows a rejuvenation of the layer and consequently of the section and thus the whole turbine assembly by material removal of the affected areas of the turbine assembly. This solution gives an effective and economical method of salvaging components that have reached the end of their initial cyclic life allowing them to be returned to engine service resulting in significant cost savings to overhauled assemblies and supply chain. There is a substantial environmental and energy saving benefit in not scrapping the turbine assembly which necessitates re-melting, re-forging and re-machining which also carries the attendant risk of being sentenced as scrap at any point of the process for reasons such as material defect, incorrect dimensions during machining or handling damage. The re-machining cost of the section and associated non-destructive testing is minimal compared to the cost of the production of the turbine assembly or parts thereof, like a disc forging, disc machining, curvic or hirth teeth and formation of blade roots. Moreover, by treating the layered section further operating time of the section can be gained.

[0038] Definitions or explanations given in the text above should also apply to the embodiments of the second aspect of the invention or should be understood analogously.

[0039] The amount of material being added by overlaying the section or a nominal surface thereof, can be determined analogously to the determination of the amount of material to be removed according to the method presented in the first aspect of the invention. However, it may be also possible to add more or less material depending on the actual properties of the turbine assembly or its section. Moreover, also the amount of material being removed from the layered section can be determined with the above stated principles or methods.

[0040] The material added might be the same material as the material of the section or it may be another material or material combination, like a protective coating. Preferably, the added material is the same material as the material of the section. Hence, the same material properties apply and the same effects on the material of the layer can be expected.

[0041] Advantageously, the method comprises the further step of: treating the layered section by removing a whole amount of the added material of the additional layer. Hence, the section can be refurbished effectively. Consequently, after the refurbishment the section would be exposed. Additionally, the removed material is the material of the additional layer. Further, also a removal of a depth of the section would be possible and thus an exposure of a sub-section of the

section.

[0042] According to a further aspect of the invention the material removal from the additional layer is performed in one single step. Hence, the risk of damaging the turbine assembly or the section during the refurbishment is minimised. Alternatively, the material removal from the additional layer can be performed in several steps. This provides the possibility to perform a security check of the section before each subsequent refurbishment step. Hence, by removing the material in more than one step at least the first material removal exposes a sub-layer of the layer or the section.

[0043] According to a preferred embodiment of the invention the method comprises the further step of: repeating the steps of defining the specific operating time, overlaying the section, treating the layered section and operating the section several times. Thus, the turbine assembly can be used effectively and consequently saving resources and money. Preferably, the steps are repeated till the defined specific operating time in the step defining the specific operating time is less than a difference between a maximum operating time of the layered section and the already performed operating time(s).

[0044] In summary, both aspects of the invention are focused on the same features, namely, the rejuvenation of a turbine assembly/component or part thereof by removing fatigued material after a beforehand defined specific operating time to operate the rejuvenated turbine assembly/component further.

Brief Description of the Drawings

[0045] The present invention will be described with reference to drawings in which:

FIG 1: shows a schematically and sectional view of a gas turbine engine comprising several inventive turbine assemblies,

FIG 2: shows a perspective view of a part of a turbine assembly embodied as a turbine disc of the gas turbine engine of FIG 1 comprising a cooling hole beforehand of a refurbishment,

FIG 3: shows a perspective view of the part from FIG 2 after the refurbishment,

FIG 4: shows a cross section through the turbine assembly along line IV-IV in FIG 2 comprising a bolt hole,

FIG 5: shows air transfer holes of the turbine assembly from FIG 2,

FIG 6: shows a diagram depicting a stress magnitude of 980 MPa at a surface of a cooling hole and of 600 MPa at a distance of 0.8 mm from the surface of the cooling hole during operation,

FIG 7: shows a diagram depicting crack initiation after 8086 cycles for a surface of a cooling hole which was exposed to a stress of 980 MPa during operation,

FIG 8: shows a diagram depicting crack initiation after 105143 cycles for a region being at a distance of 0.8 mm from the surface of the cooling hole from FIG 7 which was exposed to a stress of 600 MPa during operation,

FIG 9: shows a diagram depicting the life gained in dependency of the amount of material removed for different cooling holes,

FIG 10: shows a diagram depicting the life gained in dependency of the amount of material removed for different bolt holes and

FIG 11: shows a flow-chart for a refurbishment strategy according to the inventive method.

Detailed Description of the Illustrated Embodiments

[0046] The present invention is described with reference to an exemplary turbine engine 26 having a single shaft 38 or spool connecting a single, multi-stage compressor section 30 and a single, one or more stage turbine section 34. However, it should be appreciated that the present invention is equally applicable to two or three shaft engines and which can be used for industrial, aero or marine applications.

[0047] The terms upstream and downstream refer to the flow direction of the airflow and/or working gas flow through the engine 26 unless otherwise stated. If used, the terms axial, radial and circumferential are made with reference to a rotational axis 36 of the engine 26.

[0048] FIG 1 shows an example of a gas turbine engine 26 in a sectional view. The gas turbine engine 26 comprises, in flow series, an inlet 28, a compressor section 30, a combustion section 32 and a turbine section 34, which are generally arranged in flow series and generally in the direction of a longitudinal or rotational axis 36. The gas turbine engine 26 further comprises a shaft 38 which is rotatable about the rotational axis 36 and which extends longitudinally through the gas turbine engine 26. The shaft 38 drivingly connects the turbine section 34 to the compressor section 30.

[0049] In operation of the gas turbine engine 26, air 40 which is taken in through the air inlet 28 is compressed by the compressor section 30 and delivered to the combustion section or burner section 32. The burner section 32 comprises a burner plenum 42, one or more combustion chambers 44 defined by a double wall can 46 and at least one burner 48 fixed to each combustion chamber 44. The combustion chambers 44 and the burners 48 are located inside the burner plenum 42. The compressed air passing through the compressor section 30 enters a diffuser 50 and is discharged from the diffuser 50 into the burner plenum 42 from where a portion of the air enters the burner 48 and is mixed with a gaseous or liquid fuel. The air/fuel mixture is then burned and the combustion gas 52 or working gas from the combustion is channelled via a transition duct 54 to the turbine section 34.

[0050] This exemplary gas turbine engine 26 has an annular combustor section arrangement 56, which is constituted by an annular array of combustor cans 46 each having the burner 48 and the combustion chamber 44, the transition duct 54 has a generally circular inlet that interfaces with the combustion chamber 44 and an outlet in the form of an annular segment. An annular array of transition duct outlets form an annulus for channelling the combustion gases to the turbine section 34.

[0051] The turbine section 34 comprises a number of turbine assemblies 10 embodied as blade carrying discs 58 or turbine wheels 60 attached to the shaft 38. In the present example, the turbine section 34 comprises two discs 58 each carry an annular array of aerofoils 62 each embodied as a turbine blade. However, the number of blade carrying discs 58 could be different, i.e. only one disc 58 or more than two discs 58. In addition, turbine cascades 64 are disposed between the turbine blades. Each turbine cascade 64 carries an annular array of aerofoils 62 in the form of guiding vanes, which are fixed to a stator 66 of the gas turbine engine 26. Between the exit of the combustion chamber 44 and the leading turbine blades inlet guiding vanes or nozzle guide vanes 68 are provided and turn the flow of working gas 52 onto the turbine blades.

[0052] The combustion gas 52 from the combustion chamber 44 enters the turbine section 34 and drives the turbine blades which in turn rotate the shaft 38. The guiding vanes 68 serve to optimise the angle of the combustion or working gas 52 on to the turbine blades. The turbine section 34 drives the compressor section 30. The compressor section 30 comprises an axial series of guide vane stages 70 and rotor blade stages 72. The rotor blade stages 72 comprise a rotor disc 58 supporting aerofoils 62 as an annular array of turbine blades.

[0053] The compressor section 30 also comprises a stationary casing 74 that surrounds the rotor stages 72 in circumferential direction 76 and supports the vane stages 70. The guide vane stages 70 include an annular array of radially extending aerofoils 62 embodied as vanes that are mounted to the casing 74. The vanes are provided to present gas flow at an optimal angle for the blades at a given engine operational point. Some of the guide vane stages 70 have variable vanes, where the angle of the vanes, about their own longitudinal axis, can be adjusted for angle according to air flow characteristics that can occur at different engine operations conditions.

[0054] The casing 74 defines a radially outer surface 78 of a passage 80 of the compressor section 30. A radially inner surface 82 of the passage 80 is at least partly defined by a rotor drum 84 of the rotor which is partly defined by the annular array of blades.

[0055] During operation of the turbine engine 26 features of components of the engine 26, like cooling holes 18 or bolt holes 20 of the turbine assemblies 10 or the discs 58 or of the aerofoils 62 are exposed to detrimental conditions inducing internal stresses in the components. Thus, phenomena like low cycle fatigue (LCF) may occur which e.g. results in the formation of cracks. Typically, only small aspects of the components or the turbine assembly 10 reach its cycle life; the remaining features in the component are often capable of many more cycles. However, these damaged regions deem the turbine assembly 10 unfit for further operation. Hence, a repair strategy intended to rejuvenate the turbine assembly 10 and consequently, a method for operating and treating the turbine assembly 10 is proposed.

[0056] Hence, in a first step of this method a section 12 of the turbine assembly 10 that is prone to fatigue while operating the turbine assembly 10 will be determined. This may be done by inspecting the turbine assembly 10 after several operating cycles or be based on live experience or be based on calculations.

[0057] As stated above, typical locations of cyclic life limiting features are cooling holes 18 or bolt holes 20 at the turbine disc 58. Thus, the section 12 comprises a change in its contour 16 and is a hole 18, 20 with its surface 22 or rim. Changes in contour 16 or holes 18, 20 are stress raisers and increase the stress in the component at their location or around their location. Hence, a stress concentration factor is especially high for the material around the hole 18, 20. This is specifically the case for an acute corner 23 of a hole 18 with a breakout 25 that breaks out at the surface 22 of the hole 18 at an angle α .

[0058] FIG 2 to 5 show exemplarily four sections 12, 12a that are prone to fatigue while operating the turbine assembly 10, 10a. FIG 2 shows a perspective view of a part of a turbine assembly 10 embodied as a turbine disc 58 of the gas

turbine engine 26 beforehand of a refurbishment. FIG 3 shows the part of the turbine disc 58 after the refurbishment.

[0059] The turbine assembly 10 comprises a cooling hole 18 that feeds cooling medium 86 to a blade root slot 88 of the disc 58. The cooling air feed hole 18 is positioned at a bottom 90 of a blade root slot 88. After operating the turbine assembly 10 the entire hole 18 or a part of the hole 18 will show fatigue. The part of the hole 18 may be, for example, a region or section 12 embodied as an inner surface 92 of the hole 18 or the acute corner 23 of the hole 18, 20 with the breakout 25 that breaks out at the surface 22 of the hole 18 at the angle α . In FIG 4 a bolt hole 20 of a disc 58 of a multi tie bolted rotor arrangement is shown. The region or section 12 around the bolt hole 20 will show fatigue after operating the turbine assembly 10. In FIG 5 air transfer holes 18 of a disc 58 are shown. The region or section 12a around the air transfer hole 18 will show fatigue after operating the turbine assembly 10a.

[0060] To decide on a suitable refurbishment strategy several considerations are important. The stress acting on different positions of the turbine assembly 10, especially, at different distances from the stress raiser or from the surface 22 or rim of the hole 18, 20, needs to be considered. Moreover, the time until the cyclic life of the turbine assembly 10 or the section 12 or different regions thereof is reached is taken into account.

[0061] Hence, it is determined which maximum principal stress acts upon the material depending on a distance from the stress raiser, in this case the surface 22 or rim of the hole 18, 20 or from the acute corner 23. The stress at a point varies in different directions. These stresses are often expressed in terms of three "principle stresses" which occur at a specific angle which depends on the part in question and at right angles to each other. The largest of these, the "maximum principle stress" is often used to determine the life. Alternatively, a mixture of all three stresses as well as shear stresses may be used (this is known as the von Mises stress).

[0062] FIG 6 shows a diagram depicting the stress magnitude versus the perpendicular distance from stress concentration or in other words the distance from the surface 22 or rim of the cooling hole 18 having a diameter of 5.6 millimetre (mm). The y-axis refers to the maximum principle stress in megapascal (MPa) and on the x-axis the distance from the surface 22 or rim is plotted in millimetre (mm). As can be seen in the graph at the surface 22 or rim of a cooling hole 18 a stress magnitude of 980 MPa acts upon the material and at a distance of 0.8 mm from the surface 22 or rim of the cooling hole 18 a stress magnitude of 600 MPa acts upon the material during operation.

[0063] To determine the time until the cyclic life or fatigue life of the selected locations is reached strain-life curves are examined. Therefore, the maximum principle stress is converted in to a total strain range. LCF life is calculated using a computer simulation, finite element model. It models the stress versus time for 1 cycle, and then the location with the worst combination of stress range and mean stress is found. This is used to find a strain range, and then, using lifing data acquired from material specimen testing which provides a strain range versus life curve, the life can be calculated, after the curve is adjusted for the mean stress required. The time (LCF life) is represented by the amount (N) of cycles, wherein one cycle is the time from when the engine 26 is first started to when it is stopped. Usually the number of cycles the parts in question can endure is independent of the engine running time (provided the parts do not creep, which means deform over time due to high temperature and stress). Therefore, parts have a cyclic life, the higher the better. After the cyclic life is used up, cracking occurs in the part, and then failure.

[0064] The life of a part is usually determined by the highest stressed point in that part. In general, the higher the stress range at a point (i.e. the difference between the highest and lowest stress at that point during 1 cycle), the lower the number of cycles it can endure before it begins to crack. Sometimes the deformation during a cycle i.e. the "strain range" is calculated (which is related to the "stress range"), and similarly this relates to the life of the part.

[0065] The life is not only affected by the stress range, but also the average stress at the life limiting point. The higher the average stress the worse it is. Lifing is based on material testing which is done for different stress ranges. However, the conditions in the test may not mirror the exact mean stress seen in a part. Therefore, a mathematical mean stress adjustment is carried out on the test data to give life data corresponding to the desired mean stress. The R value relates to the test data, and it is the ratio of the test minimum stress/maximum stress, so $R=-1$ means the stress in the test oscillates from a compressive (which is assigned a negative value), to tensile (which is assigned a positive value), of equal magnitude.

[0066] FIG 7 and 8 show diagrams depicting strain versus the cycles to crack initiation. The y-axis refers to the total strain range in percent (%) and on the x-axis N, cycles for crack initiation is plotted (the graph with the broken line depicts the strain-life curve, $R=-1$; the graph with the chain dotted line represents the strain-life curve, mean stress adjusted, the horizontal solid lines the total strain range and the vertical broken lines the respective LCF life).

[0067] As can be deviated from the diagram of FIG 7 cracking will occur at the surface 22 or rim after 8086 cycles so that the turbine assembly 10 reaches its LCF live after 8086 cycles or has an initial life of 8086 cycles. In FIG 8 is shown that for a region being positioned 0.8 mm away from the surface 22 or rim of the hole 18 damage will occur after 105143 cycles so that this region would reach its LCF live after 105143 cycles or has an initial life of 105143 cycles. Hence, the life of a region positioned away from the hole is greater than the life at the surface 22 or rim of the hole 18.

[0068] The two lives (8086 and 105143) correspond to the different locations to the hole 18. The 8086 cycles is at the inner surface 92 of the hole 18, this highlights that this section 12 has the lowest life. However, the region 0.8 mm from the inner surface 92 of the hole 18 has a life of 105143 cycles, so this part of the turbine assembly 10 is barely damaged

after 8086 cycles (but some damage does occur). Therefore, a cumulative damage approach will be used to assess the life of the hole 18 after refurbishment.

[0069] With these two values the specific operating time of the section 12 of the turbine assembly 10 can be defined in the next step of the method for treating and operating the turbine assembly 10. The specific operating time is the time or specifically is the number of cycles the section 12 will be operated beforehand of the refurbishment.

[0070] The specific operating time is determined by a use of the Palmgren-Miner rule. Assuming equal running intervals before and after a refurbishment service, and using Miner's rule we get a service interval life (specific operating time), n_i of:

$$\sum_{i=1}^I \frac{n_i}{N_i} = 1$$

$$\frac{n_i}{8086} + \frac{n_i}{105143} = 1$$

$$n_i = 7508 \text{ cycles}$$

[0071] Hence, the section 12 is operated up to the specific operating time of 7508 cycles in the respective step of the method for treating and operating the turbine assembly 10.

[0072] Additionally, a finite element analysis (FEA) of the turbine assembly 10 or the section 12 after as well as before the refurbishment could also be done, to more accurately determine the stresses.

[0073] After this operating the section 12 is refurbished or treated by material removal and depending on the damaged section 12 the acute corner 23 and/or a material layer between the surfaces 92 and 94 is removed. Due to this a sub-section 14 of the section 12 with a surface 94 is exposed (see broken line in FIG 3). This sub-section 14 is operated further. The further operating time was also gained out of the Palmgren-Miner rule and is also 7508 cycles. Operating the turbine assembly 10 and thus the section 12 and the sub-section 14 for 7508 cycles before and after refurbishment gives the same level of damage as running for 8086 cycles without refurbishment.

[0074] The amount of material to be removed is determined by a consideration of at least one of the factors consisting out of the group of: internal stress, contact stress, temperature, material capability, material thickness, operating speed, flow velocity of a flow medium and desired future fatigue life as well as by at least one of the methods out of the group consisting of: Finite Element Analysis, hand calculations, obtaining results from laboratory testing or from examination of engine run components and applying statistics over the results.

[0075] FIG 9 and 10 show the results of Finite Element Analysis of discs out of different materials and having cooling or bolt holes 18, 20 with different diameters, geometries or orientations. In each diagram the y-axis refers to the life gained as percent (%) of initial life if this much material is removed and on the x-axis the distance from the hole as percent (%) of the hole radius is plotted (Legend for the graphs in FIG 9 specifying the material of the disc, hole diameter and orientation of the respective cooling hole 18: graph with broken line and diamond symbol: IN718, 12.5 mm; graph with chain dotted line and rectangle symbol: steel, 16 mm; graph with chain dotted line and triangle symbol: steel, 7 mm; graph with light solid line and cycle symbol: steel, 5.6 mm; graph with solid line and asterisk symbol: IN718, 5.6 mm, vertical; graph with bold solid line and cycle symbol: IN718, 5.6 mm, angled (peak stress on obtuse corner); Note: for the first five graphs the peak stress is on an acute corner; Legend for the graphs in FIG 10 specifying the material of the disc, hole diameter and load factor increase of the respective bolt hole 20: graph with solid line and cycle symbol: IN718, 34 mm; graph with chain dotted line and triangle symbol: IN718, 42.8 mm; graph with solid line and asterisk symbol: IN718, 34 mm, 1.45 load; graph with broken line and diamond symbol: IN718, 42.8 mm, 1.2 load).

[0076] As could be seen in FIG 9 a life gain of 60% and even up to 70% can be obtained by removing 10% of the distance from the radius of a cooling hole 18. By removing 25% up to 95% life gain can be achieved. In the case of the bolt holes 20, as shown in FIG 10, the removal of 10% results in a life gain of about 40% or even up to 85%. By removing 30% a life gain of about 70% can be achieved.

[0077] Hence, it was found, that by treating the section 12 by material removal by enlarging a diameter d of the hole 18, 20 or by removing material from or the "whole" acute corner 23 of the hole 18 with the breakout 25 that breaks out at the surface 22 of the hole 18 at the angle α , and especially, by removing about 10% to 30% of the diameter d from the inner surface 92 or at the acute corner 23 a significant effect on the life was gained without compromising the overall integrity of the section 12 and the turbine assembly 10. These figures were determined as the range that would give optimal life recovered for as little services as possible (or within acceptable/scheduled levels of serving), with acceptable levels of material removal. The amount of material removed would vary from part to part, and from service strategy to service strategy, and will be chosen from the person skilled in the art according to its knowledge in the field.

[0078] As can be seen by comparing the results for the cooling holes 18 (see FIG 9) and the bolt holes 20 (FIG 10)

the effects of the refurbishment is more effective for the cooling holes 18, especially, angled holes with the peak stress at the acute corner 23 (see all graphs in FIG 9 except the graph with bold solid line and cycle symbol). Thus, more material is generally needed to be removed for the bolt holes 20 to gain the same amount of life as for a cooling hole 18. This is because the geometry at a bolt hole 20 is usually slightly different from a cooling hole 18 resulting in a lower stress "raiser" (a stress raiser - also known as a stress concentration factor - is where the geometry causes the stress to increase as it nears the feature - hole - in question). This is usually the case when the cooling hole 18 has the breakout 25 that breaks out at the angle α ; and the peak stress usually occurs at the acute corner 23 of the breakout 25. This refurbishment technique works better when the stress is especially high close to the hole 18, which is more the case with the cooling holes 18 due to the higher stress concentration factor. Hence, the material removal of 10% to 20% may be enough for a cooling hole 18 and should be up to 30% for a bolt hole 20.

[0079] The above stated findings will now be summarised exemplarily for a steel disc with a hole having a diameter of 5.6 mm (see graph with light solid line and cycle symbol in FIG 9). Assuming equal number of damage cycles for the 980 MPa and 600 MPa cycles and using Miner's rule the life is 7508 joint cycles (where one joint cycle includes one 980 MPa cycle and one 600 MPa cycle). The life of a cooling hole 18 is 7508 cycles, then if it were refurbished by increasing the diameter of the hole from the original diameter of 5.6 mm to the rework diameter of 7.2 mm (28.6% increase by enlarging the diameter about 1.6 mm or by removing 0.8 mm from the acute corner 23 of the hole 18 at the region of the breakout 25, respectively) and the part of the disc that was at 600 MPa, then was subjected to a stress of 980 MPa, it could do another 7508 cycles. Therefore, in theory the life of the 5.6 mm cooling hole 18 would potentially increase from 8086 engine cycles to 15016 engine cycles.

[0080] The method may comprise a single refurbishment step or more than one. Hence, the method comprises the further step of: repeating the steps of defining the specific operating time, operating the section 12, treating the section 12 and operating the sub-section 14 several times. The refurbishment process could be repeated and more life gained for the section 12 or the hole 18, 20, although the life gained after each refurbishment would gradually drop.

[0081] As the stress versus distance from the hole curves basically offset after a refurbishment step, i.e. it is like starting the stress versus distance from the hole curve again, the amount of material removed in the further refurbishment step(s) and how many times it was done will be selected so that a balance was reached between the gaining of enough life to make the process worthwhile and permitting space and the overall integrity of the part. Although analysis of the turbine assembly 10 or the section 12 before or after the refurbishment can be done to accurately determine the stresses.

[0082] The repetition can be done until an abort criterion is reached and for example until the defined operating time in the step defining the operating time is less than a difference between a maximum operating time of the section 12 and the already performed operating time(s).

[0083] In FIG 11 a flow chart of a possible component refurbishment strategy is shown. After operating the component or turbine assembly 10 for a pre-defined time, like routinely 5000 cycles or routinely 1 to 4 years, operator or service records are interrogated to determine if the assembly 10 has sufficient cyclic life to make it to the next service. If yes, the assembly 10 is inspected out of security reasons and if no objections are raised it is returned to service to operate a further time, like routinely 5000 cycles or routinely 2 to 4 years.

[0084] If the interrogation results in a negative result (decision no) e.g. when the selected operating time has reached the value of the 7508 cycles disclosed above, it is checked if the assembly 10 or its section 12 has reached its rework limit. Exceeding the rework limit may compromise the overall integrity of the section 12 or assembly 10. If the rework limit is reached (decision yes) the assembly 10 is scrapped. If the answer is no the section 12 would be refurbished or reworked, respectively. Thereafter, the assembly 10 is inspected out of security reasons and if no objections are raised it is returned to service to operate a further time e.g. the further 7508 cycles disclosed above.

[0085] In reference to FIG 5 an alternative method for operating and treating a turbine assembly will be described. Components, features and functions that remain identical are in principle substantially denoted by the same reference characters. To distinguish between the embodiments, however, the letter "a" has been added to the different reference characters of the embodiment in FIG 1 to 4. The following description is confined substantially to the differences from the embodiment in FIG 1 to 4, wherein with regard to components, features and functions that remain identical reference may be made to the description of the embodiment in FIG 1 to 4.

[0086] FIG 5 shows a turbine assembly 10a being refurbished with an alternative method for operating and treating the turbine assembly 10a. The method from FIG 5 differs in regard to the method used in the embodiment according to FIG 1 to 4 in that after determining a section 12a of the turbine assembly 10a that is prone to fatigue while operating the turbine assembly 10a the section 12a or its surface 92 is overlain with an additional depth of material to form an additional layer 24 of material providing an outer surface 96 (see broken lines in FIG 5).

[0087] After a defining of a specific operating time of the layered section 12a and subsequently, an operating of the turbine assembly 10a up to the specific operating time the layered section 12a or layer 24 is treated by material removal from the additional layer 24 of material or its surface 96. Afterwards the section 12a is operated further.

[0088] Preferably, a whole amount of the added material of the additional layer 24 of the layered section 12 is removed in the treatment step. Hence, the original surface 22 or rim or the surface 92 of the hole 18 is exposed. It is possible to

either perform the material removal from the additional layer 24 in one step or in several steps. Hence, the method comprises the step of repeating the steps of defining the specific operating time, overlaying the section 12a, treating the layered section 12a and operating the section 12a several times. This may be done till an abort criterion or a work limit is reached. This may be when the defined specific operating time in the step defining the specific operating time is less than a difference between a maximum operating time of the layered section 12a and the already performed operating time(s).

[0089] It should be noted that the term "comprising" does not exclude other elements or steps and "a" or "an" does not exclude a plurality. Also elements described in association with different embodiments may be combined. It should also be noted that reference signs in the claims should not be construed as limiting the scope of the claims.

[0090] Although the invention is illustrated and described in detail by the preferred embodiments, the invention is not limited by the examples disclosed, and other variations can be derived therefrom by a person skilled in the art without departing from the scope of the invention.

Claims

1. Method for operating and treating a turbine assembly (10), wherein the method comprises at least the steps of:

- determining at least a section (12) of the turbine assembly (10) that is prone to fatigue while operating the turbine assembly (10),
- defining a specific operating time of the section (12) of the turbine assembly (10),
- operating the section (12) up to the specific operating time,
- treating the section (12) that is prone to fatigue after operating the section (12) up to the specific operating time by material removal and thus expose a sub-section (14) of the section (12) and
- operating the sub-section (14).

2. Method according to claim 1, wherein the method comprises the further step of:

- determining the amount of material to be removed by a consideration of at least one of the factors consisting out of the group of: internal stress, contact stress, surface stress, temperature, material capability, material thickness, operating speed, flow velocity of a flow medium and desired future fatigue life.

3. Method according to claim 1 or 2, wherein the method comprises the further step of:

- determining the amount of material to be removed by at least one of the methods out of the group consisting of: Finite Element Analysis, hand calculations, obtaining results from laboratory testing or from examination of engine run components and applying statistics over the results.

4. Method according to any one of the preceding claims, wherein the method comprises the further step of:

- determining the specific operating time by a use of the Palmgren-Miner rule.

5. Method according to any one of the preceding claims, wherein the section (12) is a section (12) comprising a change in its contour (16).

6. Method according to any one of the preceding claims, wherein the section (12) is a hole (18, 20) with its surface (22).

7. Method according to claim 6, wherein the hole (18, 20) is a cooling hole (18) or a bolt hole (20).

8. Method according to claim 6, wherein the method comprises the further step(s) of:

- treating the section (12) by material removal by enlarging a diameter (d) of the hole (18, 20), especially, by removing about 10% to 30% of the diameter (d) of the hole (18, 20) and/or

- treating the section (12) by material removal from an acute corner (23) of a hole (18, 20) with a breakout (25) that breaks out at a surface (22) of the hole (18, 20) at an angle (α), especially, by removing about 10% to 30% of a diameter (d) of the hole (18, 20) with the breakout (25) at the acute corner (23).

9. Method according to any one of the preceding claims, wherein the method comprises the further step of:

- repeating the steps of defining the specific operating time, operating the section (12), treating the section (12) and operating the sub-section (14) several times.

10. Method according to any one of the preceding claims, wherein the method comprises the further step of:

- repeating the steps of defining the specific operating time, operating the section (12), treating the section (12) and operating the sub-section (14) several times until the defined operating time in the step defining the operating time is less than a difference between a maximum operating time of the section (12) and the already performed operating time(s).

11. Method for operating and treating a turbine assembly (10a), wherein the method comprises at least the steps of:

- determining at least a section (12a) of the turbine assembly (10a) that is prone to fatigue while operating the turbine assembly (10a),
 - overlaying the section (12a) with an additional depth of material to form an additional layer (24) of material,
 - defining a specific operating time of the layered section (12a),
 - operating the turbine assembly (10a) up to the specific operating time,
 - treating the layered section (12a) by material removal from the additional layer (24) of material and
 - operating the section (12a).

12. Method according to claim 11, wherein the method comprises the further step of:

- treating the layered section (12a) by removing a whole amount of the added material of the additional layer (24).

13. Method according to claim 11 or 12, wherein the material removal from the additional layer (24) is performed in one step or in several steps.

14. Method assembly to any one of claims 11 to 13, wherein the method comprises the further step of:

- repeating the steps of defining the specific operating time, overlaying the section (12a), treating the layered section (12a) and operating the section (12a) several times and especially, until the defined specific operating time in the step defining the specific operating time is less than a difference between a maximum operating time of the layered section (12a) and the already performed operating time(s).

15. Method according to any one of claims 11 to 14, wherein the method comprises the further steps of:

- determining the amount of material to be removed by a consideration of at least one of the factors consisting out of the group of: internal stress, contact stress, surface stress, temperature, material capability, material thickness, operating speed, flow velocity of a flow medium and desired future fatigue life and/or - determining the amount of material to be removed by at least one of the methods out of the group consisting of: Finite Element Analysis, hand calculations, obtaining results from laboratory testing or from examination of engine run components and applying statistics over the results and/or - determining the specific operating time by a use of the Palmgren-Miner rule and/or wherein the section (12a) is a section (12a) comprising a change in its contour (16) and/or wherein the section (12a) is a hole (18, 20) with its surface (22) and/or wherein the hole (18, 20) is a cooling hole (18) or a bolt hole (20) and/or wherein the method comprises the further step(s) of: treating the section (12a) by material removal by enlarging a diameter (d) of the hole (18, 20), especially, by removing about 10% to 30% of the diameter (d) of the hole (18, 20) and/or wherein the method comprises the further step of:

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treating the section (12) by material removal from an acute corner (23) of a hole (18, 20) with a breakout (25) that breaks out at a surface (22) of the hole (18, 20) at an angle (α), especially, by removing about 10% to 30% of a diameter (d) of the hole (18, 20) with the breakout (25) at the acute corner (23).

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FIG 1

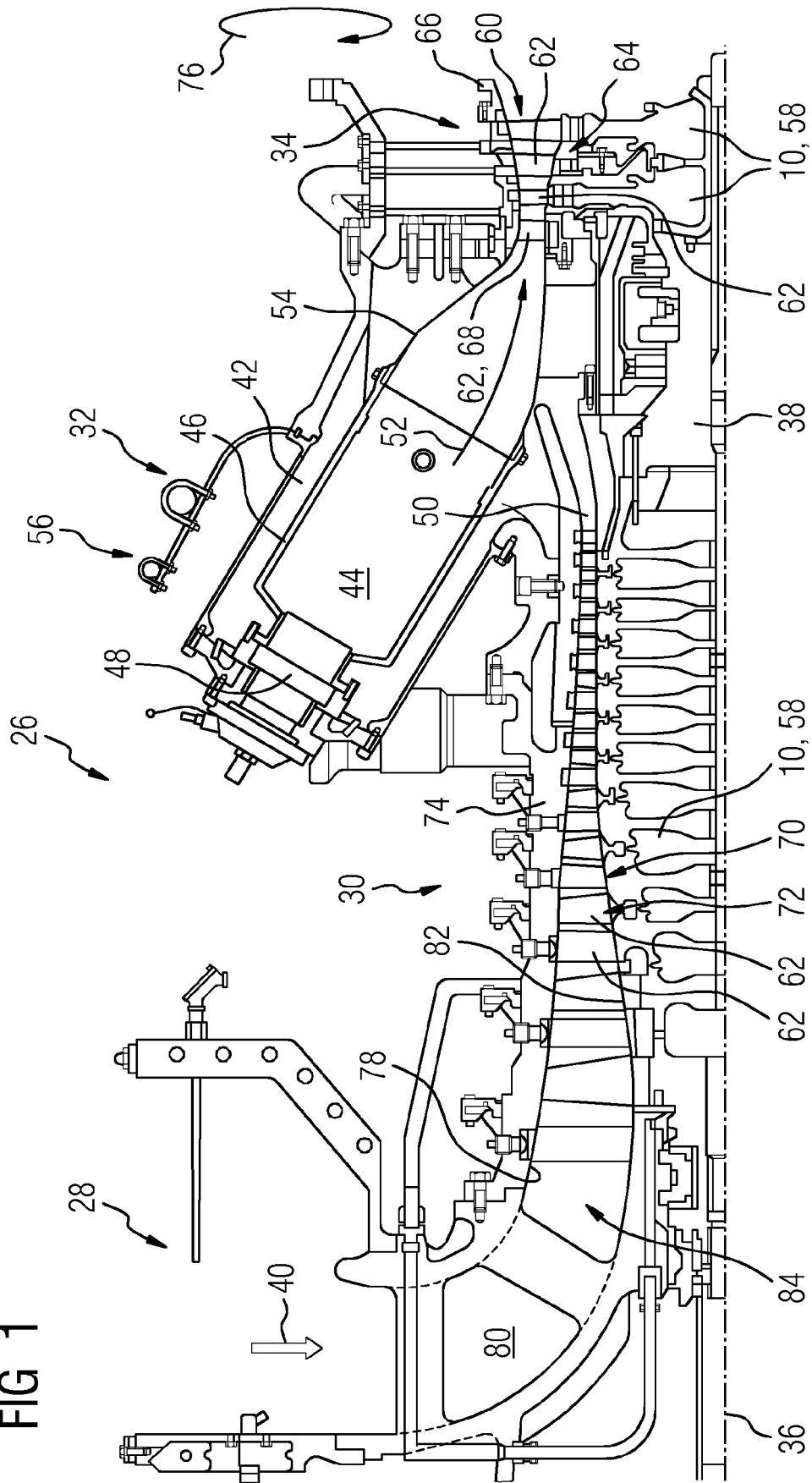


FIG 2

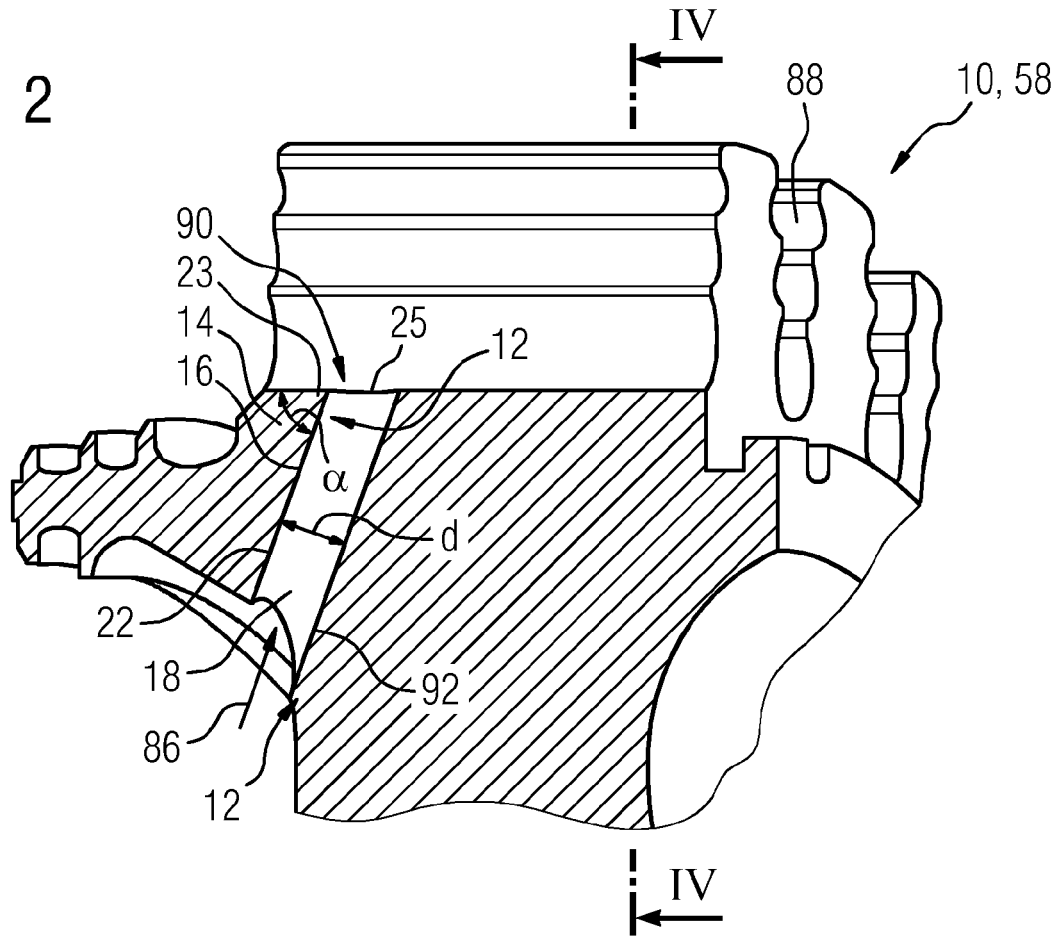


FIG 3

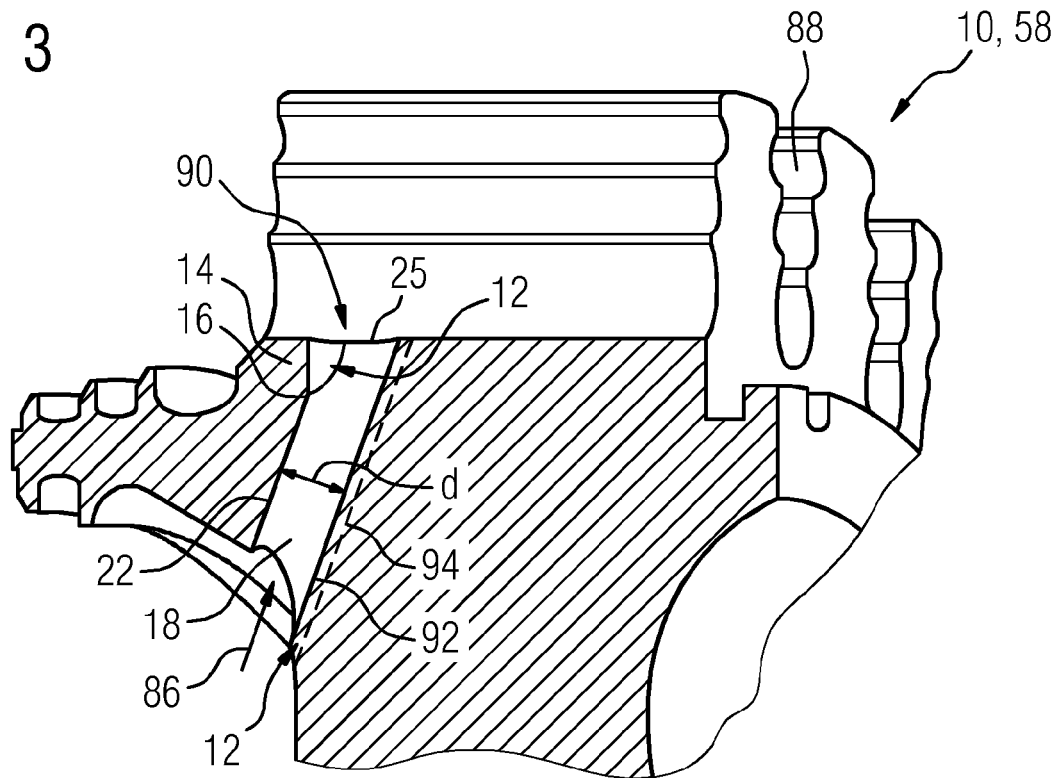


FIG 4

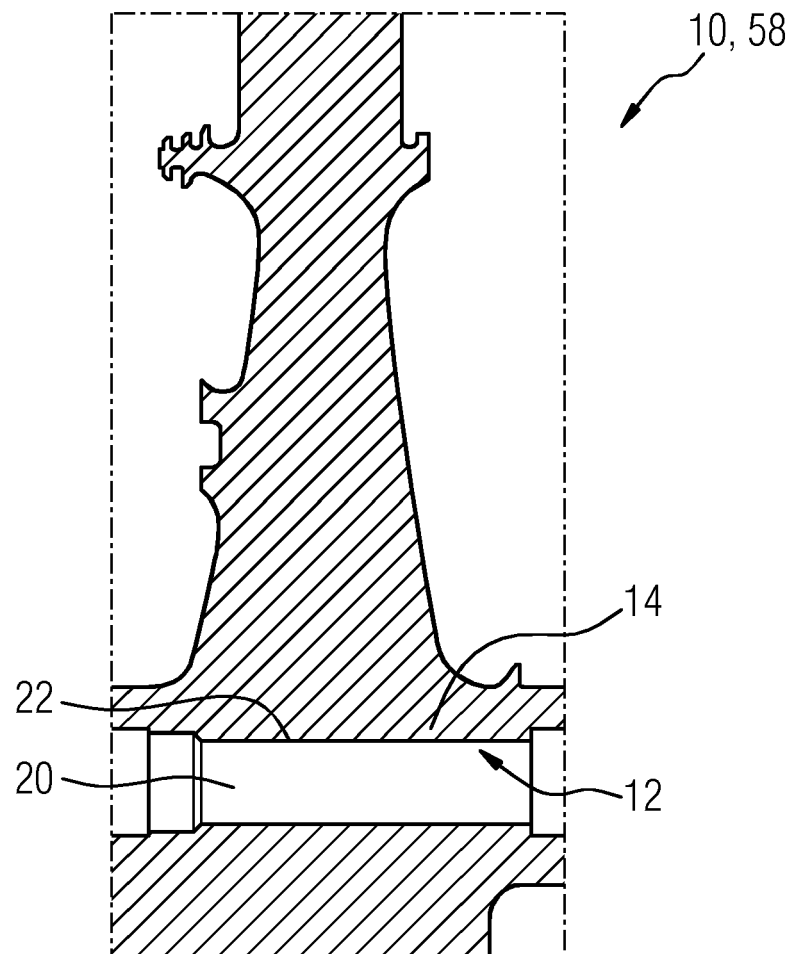


FIG 5

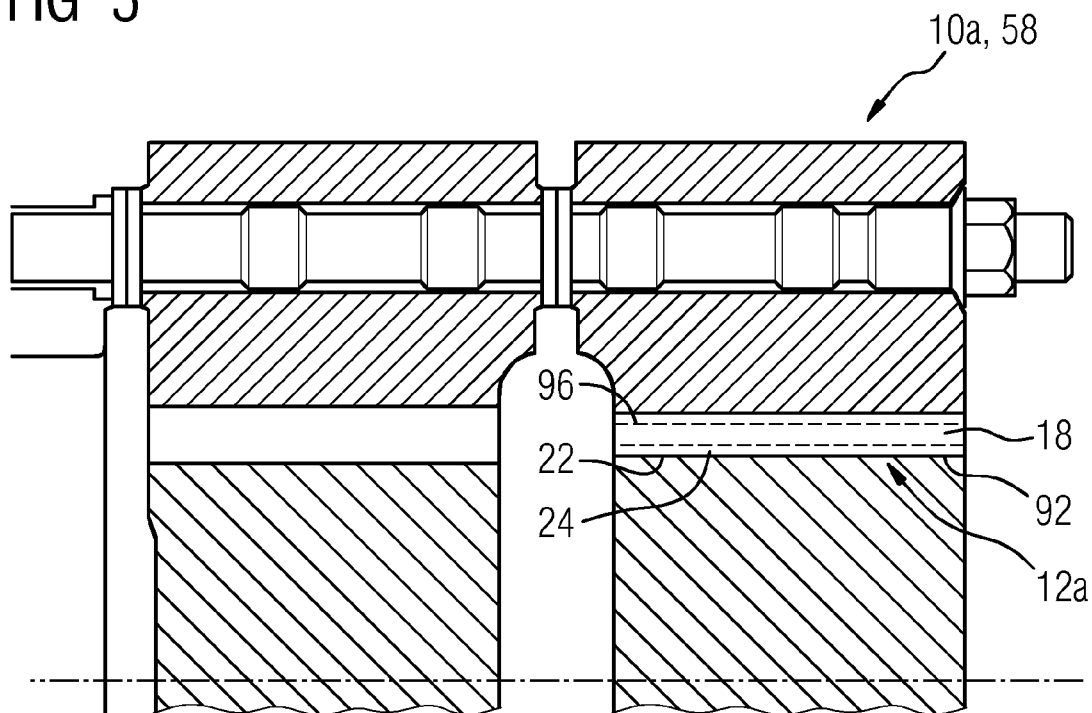


FIG 6

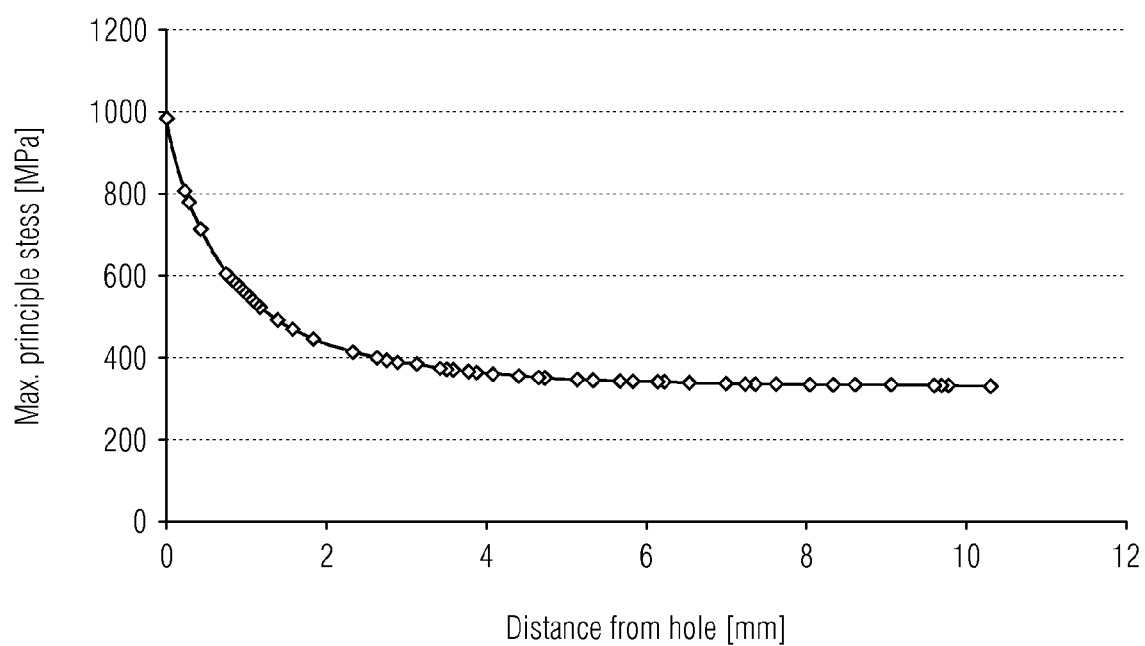


FIG 7

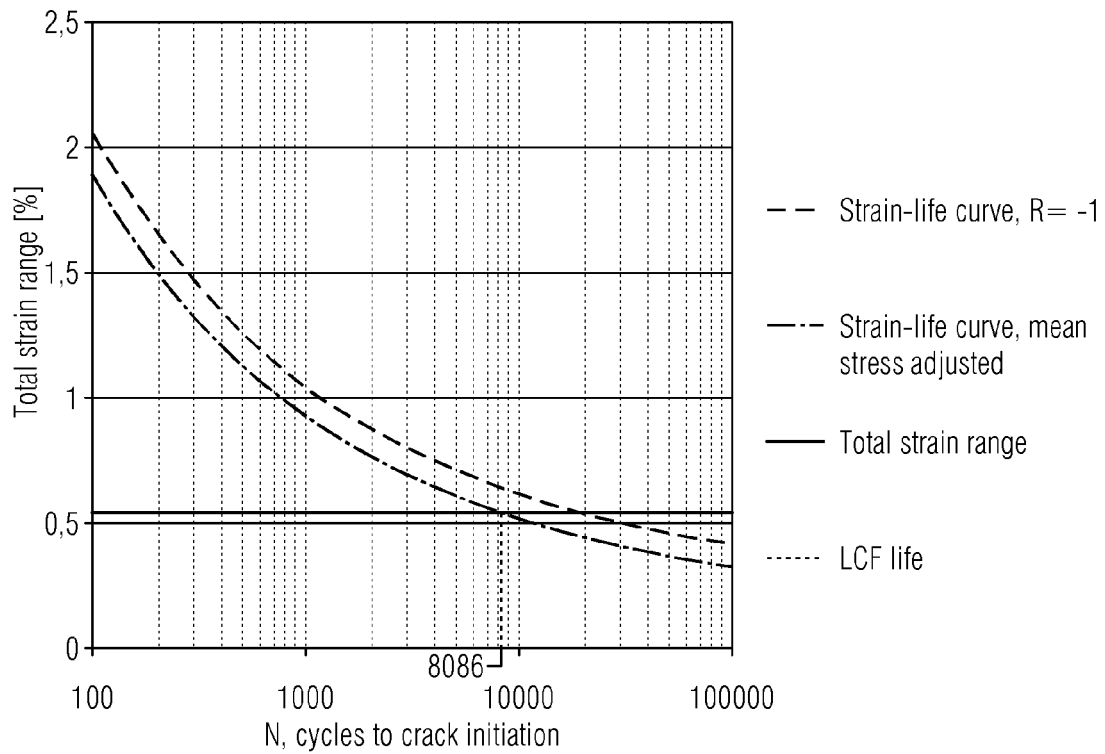


FIG 8

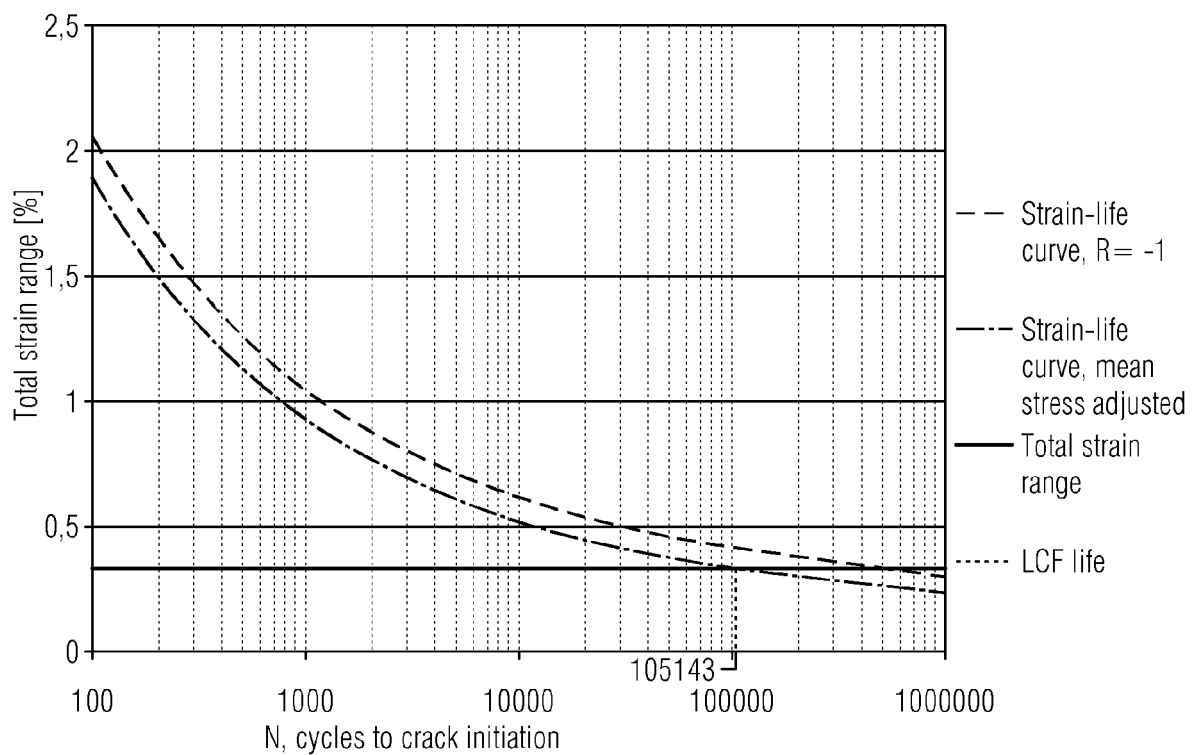
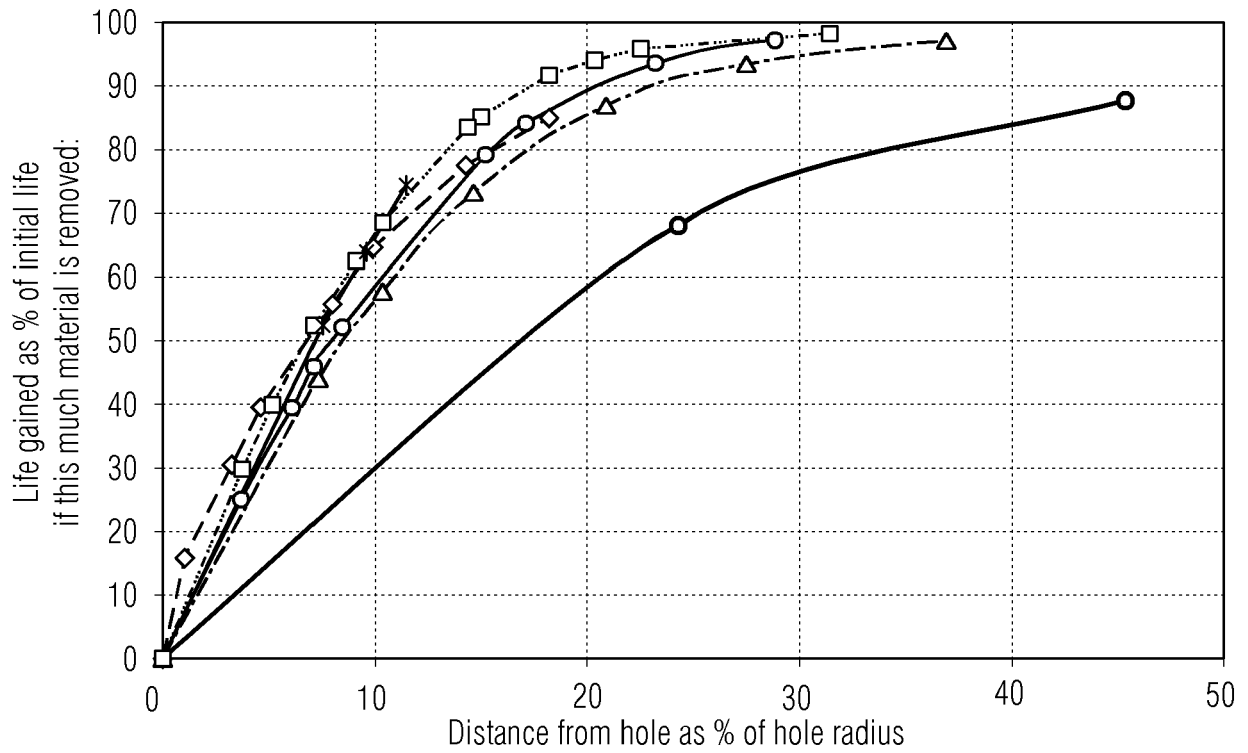


FIG 9



- ◇— IN 718 disc, Ø 12.5 mm cooling hole
 - Steel disc, Ø 16 mm cooling hole
 - △— Steel disc, Ø 7 mm cooling hole
 - Steel disc, Ø 5.6 mm cooling hole
 - *— IN 718, vertical, Ø 5.6 mm cooling hole
 - IN 718, angled, Ø 5.6 mm cooling hole
- (peak stress on acute corner)
- (peak stress on obtuse corner)

FIG 10

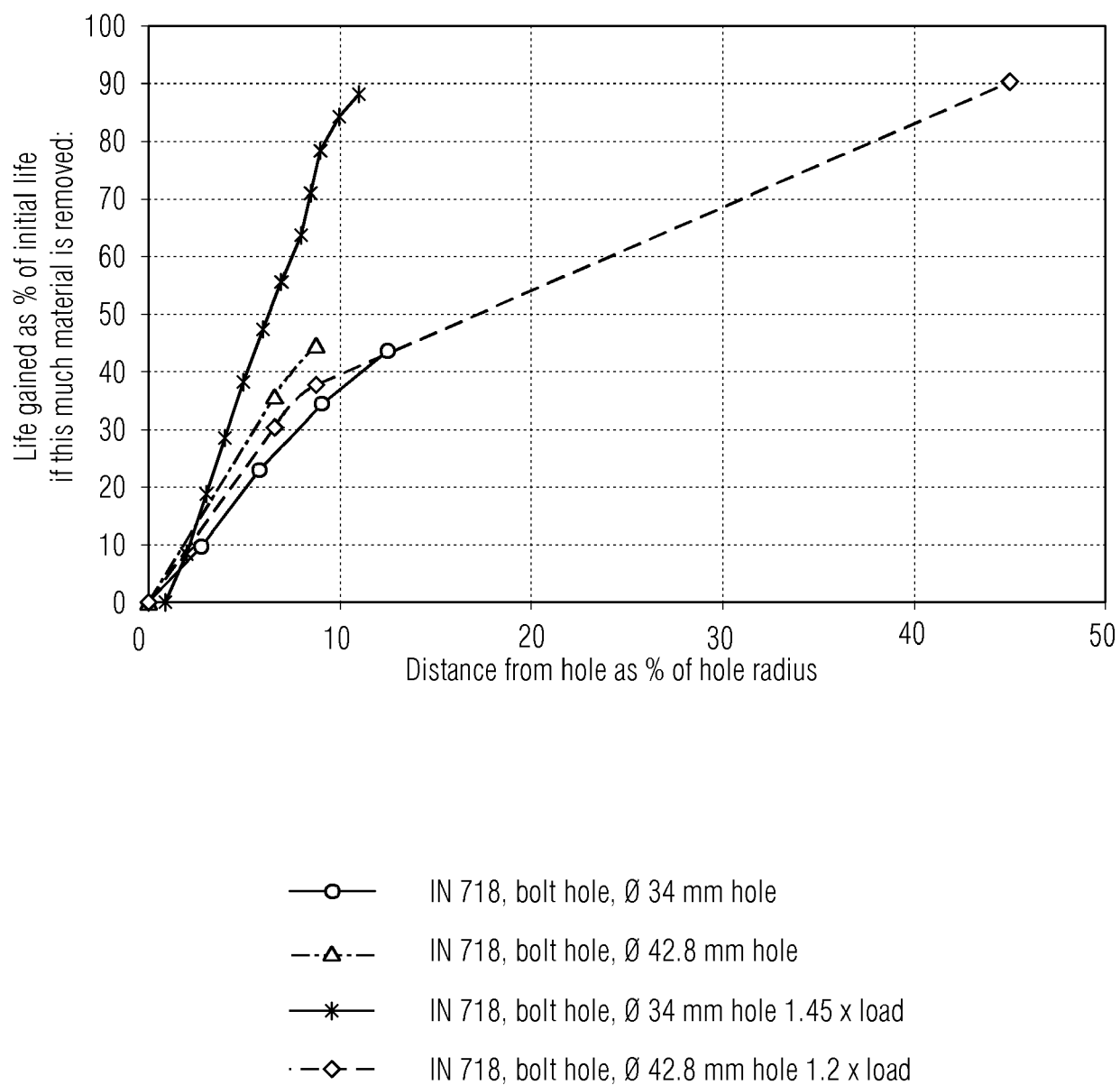
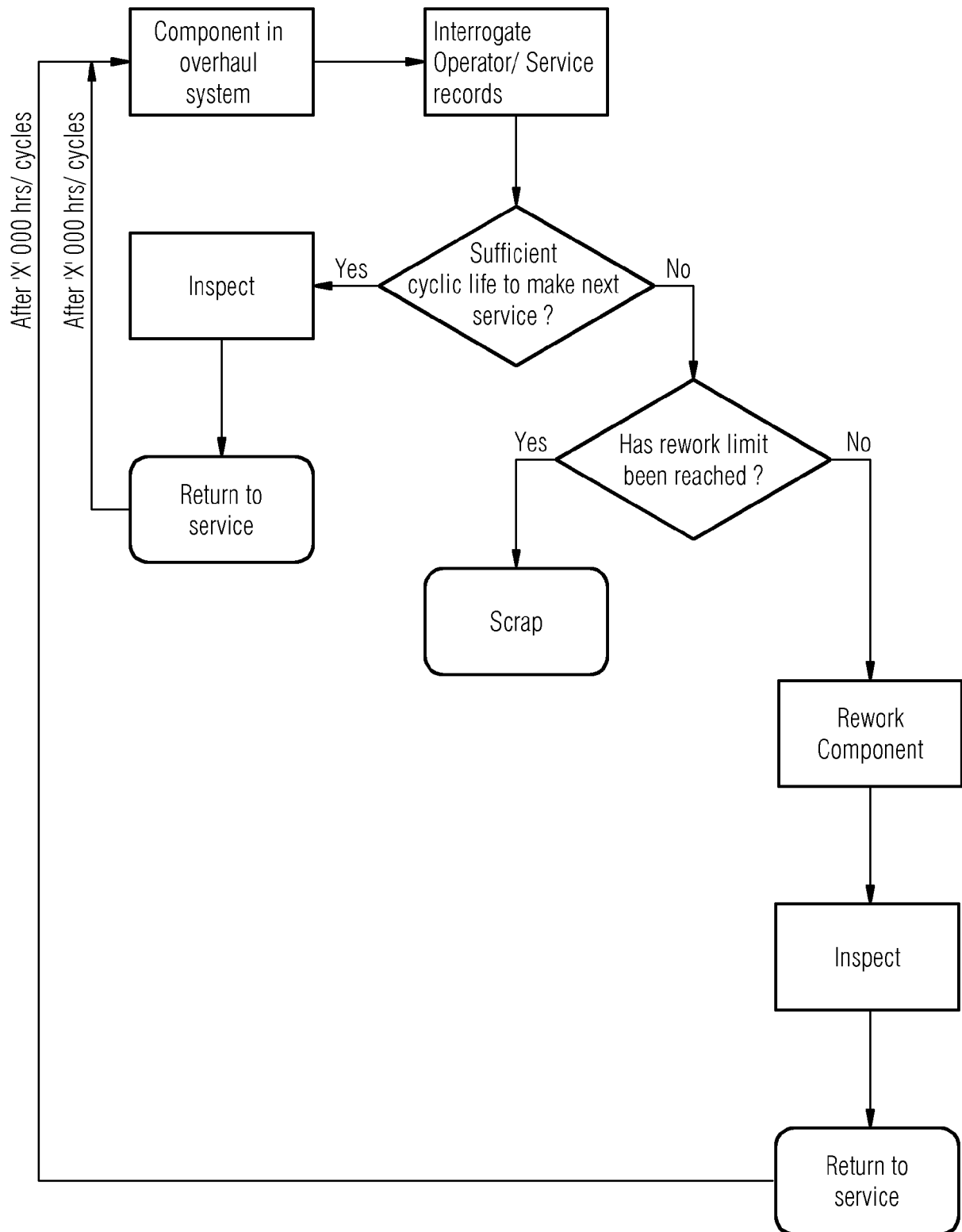


FIG 11





EUROPEAN SEARCH REPORT

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X	US 2004/115056 A1 (PIERRE SYLVAIN [US]) 17 June 2004 (2004-06-17) * paragraphs [0002] - [0004] * * paragraphs [0020] - [0029] * * claims 1-7 * * figures 2-5 *	1-15	INV. F01D5/00
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A	* paragraphs [0002] - [0005] * * paragraphs [0014] - [0022] * * figures 1-3 *	2-15	
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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 8 March 2017	Examiner Calabrese, Nunziante
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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08-03-2017

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