

FLEXIBLE ELECTROMAGNETIC SURFACE REWORK SYSTEM AND METHOD

BACKGROUND

5 **[0001]** The present disclosure relates to a system and method to rework a complex surface geometry component.

[0002] Gas turbine engines, such as those that power modern commercial and military aircraft, generally include a compressor section to pressurize an airflow, a combustor section to burn a hydrocarbon fuel in the presence of the pressurized air, and a turbine section to
10 extract energy from the resultant combustion gases.

[0003] The compressor section includes a case circumscribing an engine axis that contains axially alternating arrays of stationary vanes and rotors. Each or particular rotors may be an integrally bladed rotor (IBR) or "blisk" that includes a multiple of blades integral with a respective rotor disk.

15 **[0004]** The normal manufacture process of IBRs and other precision engineered aerospace components may result in a blemish that requires rework or other surface finish reformations to relatively complex surface geometry such as an airfoil of the IBR. Various methods of precision controlled rework requires surface/contour scanning of the geometry to be reworked before Computerized Numerical Control (CNC) abrasive belt blending/polishing is
20 performed. Although effective, such surface/contour scanning may be relatively slow and

expensive. In addition, the abrasive belt blending/polishing is typically performed with a five-axis robotic arm to access space constrained areas typical of geometrically complex components. Such equipment only further increases rework expense.

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SUMMARY

[0005] A method of reworking at least a portion of a complex surface geometry component, according to one disclosed non-limiting embodiment of the present disclosure includes applying a polarized abrasive media to a blemish on a complex surface geometry component; attaching a flexible electromagnetic polishing head to the complex surface geometry component adjacent to the polarized abrasive media; and generating an electromagnetic field with the flexible electromagnetic polishing head to affect the polarized abrasive media and thereby polish the workpiece to at least partially reduce the blemish.

[0006] A further embodiment of the present disclosure includes, wherein temporarily attaching the flexible electromagnetic polishing head to the complex surface geometry component.

[0007] A further embodiment of any of the foregoing embodiments of the present disclosure includes, temporarily attaching the flexible electromagnetic polishing head to the complex surface geometry component with an adhesive tape.

[0008] A further embodiment of any of the foregoing embodiments of the present disclosure includes, temporarily attaching the flexible electromagnetic polishing head to the complex surface geometry component such that only a boundary rail of the flexible electromagnetic polishing head contacts the complex surface geometry component.

5 [0009] A further embodiment of any of the foregoing embodiments of the present disclosure includes, containing the polarized abrasive media within the boundary rail.

[0010] A further embodiment of any of the foregoing embodiments of the present disclosure includes, selectively injecting the polarized abrasive media through a port in the boundary rail.

10 [0011] A further embodiment of any of the foregoing embodiments of the present disclosure includes, attaching the flexible electromagnetic polishing head to the complex surface geometry component at least partially over the polarized abrasive media.

[0012] A further embodiment of any of the foregoing embodiments of the present disclosure includes, attaching the flexible electromagnetic polishing head to a convex sidewall of
15 an airfoil that at least partially forms the complex surface geometry component.

[0013] A further embodiment of any of the foregoing embodiments of the present disclosure includes, attaching the flexible electromagnetic polishing head to a concave sidewall of an airfoil that at least partially forms the complex surface geometry component

[0014] An electromagnetic rework system according to another disclosed non-limiting embodiment of the present disclosure includes a polarized abrasive media including at least one component capable of being affected by an electromagnetic field; and a flexible electromagnetic polishing head operable to affect the polarized abrasive media.

5 [0015] A further embodiment of any of the foregoing embodiments of the present disclosure includes, wherein the flexible electromagnetic polishing head is capable of being flexed to follow at least a portion of a complex surface geometry component.

[0016] A further embodiment of any of the foregoing embodiments of the present disclosure includes, wherein the flexible electromagnetic polishing head is capable of being
10 flexed to follow at least a portion of a convex sidewall of an airfoil that at least partially forms the complex surface geometry component.

[0017] A further embodiment of any of the foregoing embodiments of the present disclosure includes,, wherein the flexible electromagnetic polishing head is capable of being flexed to follow at least a portion of a concave sidewall of an airfoil that at least partially forms
15 the complex surface geometry component.

[0018] A further embodiment of any of the foregoing embodiments of the present disclosure includes, a controller operable to selectively actuate a multiple of electromagnetics of the flexible electromagnetic polishing head.

[0019] A further embodiment of any of the foregoing embodiments of the present disclosure includes, wherein the multiple of electromagnetics of the flexible electromagnetic are arranged in zones.

[0020] A further embodiment of any of the foregoing embodiments of the present disclosure includes,, wherein the zones are concentrically arranged.

[0021] A further embodiment of any of the foregoing embodiments of the present disclosure includes,, wherein the zones are arranged generally in parallel.

[0022] A further embodiment of any of the foregoing embodiments of the present disclosure includes, wherein the flexible electromagnetic polishing head a includes a boundary rail to at least partially contain the polarized abrasive media.

[0023] A further embodiment of any of the foregoing embodiments of the present disclosure includes, a port in the boundary rail.

[0024] A further embodiment of any of the foregoing embodiments of the present disclosure includes wherein the flexible electromagnetic polishing head provides a magnetohydrodynamic drive.

[0025] The foregoing features and elements may be combined in various combinations without exclusivity, unless expressly indicated otherwise. These features and elements as well as the operation thereof will become more apparent in light of the following

description and the accompanying drawings. It should be understood, however, the following description and drawings are intended to be exemplary in nature and non-limiting.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0026] Various features will become apparent to those skilled in the art from the following detailed description of the disclosed non-limiting embodiments. The drawings that accompany the detailed description can be briefly described as follows:

[0027] Figure 1 is a schematic cross-section of an example gas turbine engine;

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[0028] Figure 2 is a schematic cross-section of another example gas turbine engine;

[0029] Figure 3 is a schematic expanded cross-section of a portion of an engine case with a multiple of rotor disks;

[0030] Figure 4 is a front view of a rotor disk as an example workpiece with a blemish;

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[0031] Figure 5 is a perspective view of an airfoil as an example workpiece with a complex surface geometry;

[0032] Figure 6 is a flowchart illustrating a method to rework a workpiece with a blemish according to one disclosed non-limiting embodiment;

[0033] Figure 7 is an expanded cross-sectional view of a flexible electromagnetic polishing head for use with the method of Figure 6;

[0034] Figure 8 is a bottom view of a flexible electromagnetic polishing head according to one disclosed non-limiting embodiment;

5 [0035] Figure 9 is a bottom view of a flexible electromagnetic polishing head according to another disclosed non-limiting embodiment;

[0036] Figure 10 is a bottom view of a flexible electromagnetic polishing head according to another disclosed non-limiting embodiment; and

[0037] Figure 11 is a bottom view of a flexible electromagnetic polishing head
10 according to another disclosed non-limiting embodiment.

DETAILED DESCRIPTION

[0038] Figure 1 schematically illustrates a gas turbine engine 20. The gas turbine engine 20 is disclosed herein as a two-spool turbo fan that generally incorporates a fan section
15 22, a compressor section 24, a combustor section 26 and a turbine section 28. Alternative engine architectures 10 might include an augmentor section 12 and exhaust duct section 14 (Figure 2) among other systems or features. The fan section 22 drives air along a bypass flowpath and into a compressor section 24 which drives air along a core flowpath for compression and communication into the combustor section 26, then expansion through the turbine section 28.
20 Although depicted as a turbofan in the disclosed non-limiting embodiment, it should be understood that the concepts described herein are not limited to use with turbofans as the

teachings may be applied to other types of turbine engine architecture such as turbojets, turboshafts, and three-spool (plus fan) turbofans with an intermediate spool.

[0039] The engine 20 generally includes a low spool 30 and a high spool 32 mounted for rotation about an engine central longitudinal axis X relative to an engine case assembly 36 via several bearing structures 38. The low spool 30 generally includes an inner shaft 40 that interconnects a fan 42, a low pressure compressor ("LPC") 44 and a low pressure turbine ("LPT") 46. The inner shaft 40 drives the fan 42 directly or through a geared architecture 48 to drive the fan 42 at a lower speed than the low spool 30. An exemplary reduction transmission is an epicyclic transmission, namely a planetary or star gear system.

[0040] The high spool 32 includes an outer shaft 50 that interconnects a high pressure compressor ("HPC") 52 and high pressure turbine ("HPT") 54. A combustor 56 is arranged between the high pressure compressor 52 and the high pressure turbine 54. The inner shaft 40 and the outer shaft 50 are concentric and rotate about the engine central longitudinal axis A that is collinear with their longitudinal axes.

[0041] Core airflow is compressed by the LPC 44 then the HPC 52, mixed with the fuel and burned in the combustor 56, then expanded over the HPT 54 and the LPT 46. The turbines 54, 46 rotationally drive the respective low spool 30 and high spool 32 in response to the expansion.

[0042] With reference to Figure 3, the HPC 52 includes a multiple of stages with alternate stationary vane arrays 60 and rotors 62 (only three shown) along an airflow passage 64. The rotors 62 may be assembled in a stacked configuration as a compressed tie-shaft

configuration, in which a central shaft (not shown) is assembled concentrically within the rotor stack and axially secured, to generate a preload that compresses and retains the HPC rotors 62 together as a spool. Although the HPC 52 is illustrated in the disclosed non-limiting embodiment, other engine sections will also benefit herefrom. Moreover, although a particular number of stages are illustrated, it should be appreciated that any number of stages will benefit herefrom.

[0043] Each vane array 60 includes a multiple of cantilevered mounted stator vane airfoils 66 that extend in a cantilever manner from an outer platform 68 toward the engine central longitudinal axis X. The outer platform 68 is mounted to the engine case assembly 36 via, for example, segmented hooks or other interfaces. It should be understood that various vane array configurations will benefit herefrom.

[0044] Each or particular rotors 62 may be an integrally bladed rotor that includes a multiple of airfoils 72 integrally mounted to a respective rotor disk 74 (also shown in Figure 4). The outer platform 68 of the vane arrays 60 and the rotor disk 74 of the spool at least partially bounds the airflow passage 64. The multiple of cantilevered mounted stator vane airfoils 66 extend in a cantilever manner toward the engine axis X to be disposed in close proximity to the rotor disk 74 across the airflow passage 64.

[0045] With reference to Figure 4, the rotor 62B generally includes a hub 76, a rim 78, and a web 80 that radially extends therebetween. It should be appreciated that rotor disks of various configurations will also benefit herefrom.

[0046] With reference to Figure 5, each airfoil 72 includes a first sidewall 86 that may be convex and defines a suction side, and a second sidewall 88 that may be concave and define a pressure side. Sidewalls 86, 88 are joined at the leading edge 96 and at an axially spaced trailing edge 98. More specifically, the airfoil trailing edge 98 is spaced chordwise and downstream from the airfoil leading edge 96. The sidewall 86 and sidewall 88, respectively, extend longitudinally or radially outward in span from an airfoil root 90 to a tip 92.

[0047] In some cases, even under normal acceptable manufacture, the manufacture process may result in the formation of a surface blemish (illustrated schematically by area B) on the airfoil 72. An example blemish B may be a chip or scratch that is typically about a hundredth of an inch (0.25mm) in size. It should be appreciated that although a nickel based alloy airfoil 72 is utilized in this example as the workpiece, other complex surface geometry components with various blemishes and locations thereof will benefit herefrom. Furthermore, various other alloys may be reworked, repaired or remanufactured in accordance to the disclosed method.

[0048] With reference to Figure 6, one disclosed non-limiting embodiment of a rework method 200 initially includes application of a polarized abrasive media 300 over the blemish B (step 202; Figure 7). The polarized abrasive media 300 readily follows any complex contour such as that typical of the airfoil sidewall 86, 88. That is, the paste/slurry form of the polarized abrasive media 300 resolves the challenge of exactly following a complex geometric contour to be blended/polished. In one example, the polarized abrasive media 300 is similar to a Keramo super-polishing paste manufactured by Rösler Oberflächntechnik GmbH but which is polarized or otherwise processed with magnetic material such that the polarized abrasive media

300 is capable of being affected by an electromagnetic field. For example, the polarized abrasive media 300 may contain an iron component, such as, for example, ferric oxide or iron

[0049] Next, a flexible electromagnetic polishing head 302 is applied over the polarized abrasive media 300 (step 204; Figure 7). The flexible electromagnetic polishing head 302 likewise follows the complex contour such as that typical of the airfoil sidewall 86, 88. A retainer 304 such as an adhesive tape, or other retainer may be utilized to temporarily retain the flexible electromagnetic polishing head 302 to the airfoil sidewall 86, 88. It should be appreciated that various temporary attachments may alternatively be utilized.

[0050] The flexible electromagnetic polishing head 302 includes a boundary rail 306 to contain the polarized abrasive media 300 therein and adjacent to a plurality of zones 308 of one or more electromagnets operable to generate an electromagnetic field. Each of the zones 308 may possess one or more electromagnets operable to selectively generate an electromagnetic field that selectively changes polarity sequentially to excite the polarized abrasive media 300 in a magnetohydrodynamic drive type sequence such as that utilized by maglev trains. That is, the zones 308 sequentially alternate to generally operate as a linear and/or radial motor that affects the polarized abrasive media 300 to provide agitation thereof. In other words, the magnetic fields induce currents in the polarized abrasive media 300, which in turn creates forces on the polarized abrasive media 300 and also changes the magnetic field itself.

[0051] In particular disclosed non-limiting embodiments, the plurality of zones may be arranged in concentric circles of the flexible electromagnetic polishing head 302A (Figure 8),

a plurality of parallel or substantially parallel zones of the flexible electromagnetic polishing head 302B (Figure 9), a pie type arrangement of the flexible electromagnetic polishing head 302C (Figure 10) a spiral type arrangement of the flexible electromagnetic polishing head 302D (Figure 11) or other orientations operable to agitate the polarized abrasive media 300. It should
5 be understood with these embodiments, as with each of the embodiments, that the different zones 308 may be the same size or may be different sizes to excite the polarized abrasive media 300 in a desired manner to polish the workpiece.

[0052] In another disclosed non-limiting embodiment, a port 310 may be located through boundary rail 306 to facilitate injection and removal of the polarized abrasive media 300
10 without removal of the flexible electromagnetic polishing head 302 from the workpiece. That is, the port 310 permits the polarized abrasive media 300 to be refreshed.

[0053] The flexible electromagnetic polishing head 302 is functionally connected to a controller 312 to form an electromagnetic rework system 314. One skilled in the art will recognize that controller 312 may be any of a number of devices or combination of devices
15 known for controlling electromagnets, controlling voltages, or controlling current flows. Furthermore, controller 312 may be implemented in hardware, software, firmware, or any combination thereof.

[0054] In another disclosed non-limiting embodiment, the flexible electromagnetic polishing head 302 may be electrically coupled to an alternating current for selectively
20 energizing the zones 308. In this embodiment, the controller 312 may include a processor or

computer system that controls the magnitude and polarity of the electromagnetic fields generated by the different zones of the flexible electromagnetic polishing head 302 to determine the desired electromagnetic field strength and polarity needed to affect the polarized abrasive media 300.

[0055] Operation of the flexible electromagnetic polishing head 302 generates an
5 electromagnetic field that sequentially varies through the zones 308 to agitate the polarized abrasive media 300 and thereby polishes the workpiece (step 206) to remove the blemish B. The polishing mechanism is derived from the theory of linear electromagnetic induction motors -- although the zones 308 may alternatively or additionally be otherwise arranged - and operates generally by the repelling and attracting of the polarized abrasive media 300 by the flexible
10 electromagnetic polishing head 302 to affect the polarized abrasive media 300 such as that utilized for chemical mechanical polishing thin, flat semiconductor wafers as manufactured by Crystec Technology Trading GmbH.

[0056] The flexible electromagnetic polishing head 302 advantageously provides for operations in constrained spaces typical of components with complex surface geometry such as
15 an IBR as well as the repair and remanufacture of nickel alloy and other material components. The method may further be utilized "on-wing" or within a gas turbine engine without the necessity of engine disassembly. The disclosed rework method significantly reduces maintenance turn-time and cost which directly benefiting the end customer.

[0057] The use of the terms "a" and "an" and "the" and similar references in the
20 context of description (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or specifically

contradicted by context. The modifier "about" used in connection with a quantity is inclusive of the stated value and has the meaning dictated by the context (e.g., it includes the degree of error associated with measurement of the particular quantity). All ranges disclosed herein are inclusive of the endpoints, and the endpoints are independently combinable with each other. It should be appreciated that relative positional terms such as "forward," "aft," "upper," "lower," "above," "below," and the like are with reference to the normal operational attitude of the vehicle and should not be considered otherwise limiting.

[0058] Although the different non-limiting embodiments have specific illustrated components, the embodiments of this invention are not limited to those particular combinations. It is possible to use some of the components or features from any of the non-limiting embodiments in combination with features or components from any of the other non-limiting embodiments.

[0059] It should be appreciated that like reference numerals identify corresponding or similar elements throughout the several drawings. It should also be appreciated that although a particular component arrangement is disclosed in the illustrated embodiment, other arrangements will benefit herefrom.

[0060] Although particular step sequences are shown, described, and claimed, it should be understood that steps may be performed in any order, separated or combined unless otherwise indicated and will still benefit from the present disclosure.

[0061] The foregoing description is exemplary rather than defined by the limitations within. Various non-limiting embodiments are disclosed herein, however, one of ordinary skill in the art would recognize that various modifications and variations in light of the above teachings will fall within the scope of the appended claims. It is therefore to be appreciated that
5 within the scope of the appended claims, the disclosure may be practiced other than as specifically described. For that reason the appended claims should be studied to determine true scope and content.

CLAIMS

What is claimed:

1. A method of reworking at least a portion of a complex surface geometry
5 component, comprising:
applying a polarized abrasive media to a blemish on a complex surface geometry
component;
attaching a flexible electromagnetic polishing head to the complex surface geometry
component adjacent to the polarized abrasive media; and
10 generating an electromagnetic field with the flexible electromagnetic polishing head to
affect the polarized abrasive media and thereby polish the workpiece to at least
partially reduce the blemish.
2. The method as recited in claim 1, further comprising temporarily attaching the
15 flexible electromagnetic polishing head to the complex surface geometry component.
3. The method as recited in claim 1, further comprising temporarily attaching the
flexible electromagnetic polishing head to the complex surface geometry component with an
adhesive tape.

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4. The method as recited in claim 1, further comprising temporarily attaching the flexible electromagnetic polishing head to the complex surface geometry component such that only a boundary rail of the flexible electromagnetic polishing head contacts the complex surface geometry component.

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5. The method as recited in claim 4, further comprising containing the polarized abrasive media within the boundary rail.

6. The method as recited in claim 5, further comprising selectively injecting the polarized abrasive media through a port in the boundary rail.

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7. The method as recited in claim 5, further comprising attaching the flexible electromagnetic polishing head to the complex surface geometry component at least partially over the polarized abrasive media.

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8. The method as recited in claim 1, further comprising, attaching the flexible electromagnetic polishing head to a convex sidewall of an airfoil that at least partially forms the complex surface geometry component.

9. The method as recited in claim 1, further comprising, attaching the flexible electromagnetic polishing head to a concave sidewall of an airfoil that at least partially forms the complex surface geometry component.

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10. An electromagnetic rework system, comprising:
a polarized abrasive media including at least one component capable of being affected by
an electromagnetic field; and
a flexible electromagnetic polishing head operable to affect the polarized abrasive media.

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11. The system as recited in claim 10, wherein said flexible electromagnetic polishing head is capable of being flexed to follow at least a portion of a complex surface geometry component.

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12. The system as recited in claim 11, wherein said flexible electromagnetic polishing head is capable of being flexed to follow at least a portion of a convex sidewall of an airfoil that at least partially forms the complex surface geometry component.

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13. The system as recited in claim 11, wherein said flexible electromagnetic polishing head is capable of being flexed to follow at least a portion of a concave sidewall of an airfoil that at least partially forms the complex surface geometry component.

14. The system as recited in claim 10, further comprising a controller operable to selectively actuate a multiple of electromagnetics of the flexible electromagnetic polishing head.

15. The system as recited in claim 14, wherein the multiple of electromagnetics of the
5 flexible electromagnetic are arranged in zones.

16. The system as recited in claim 15, wherein said zones are concentrically arranged.

17. The system as recited in claim 15, wherein said zones are arranged generally in
10 parallel.

18. The system as recited in claim 10, wherein said flexible electromagnetic polishing head includes a boundary rail to at least partially contain said polarized abrasive media.

15 19. The system as recited in claim 18, further comprising a port in the boundary rail.

20. The system as recited in claim 10, wherein said flexible electromagnetic polishing head provides a magnetohydrodynamic drive.

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