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(54) **TOOLING ASSEMBLY FOR DECREASING POWDER USAGE IN A POWDER BED ADDITIVE MANUFACTURING PROCESS**

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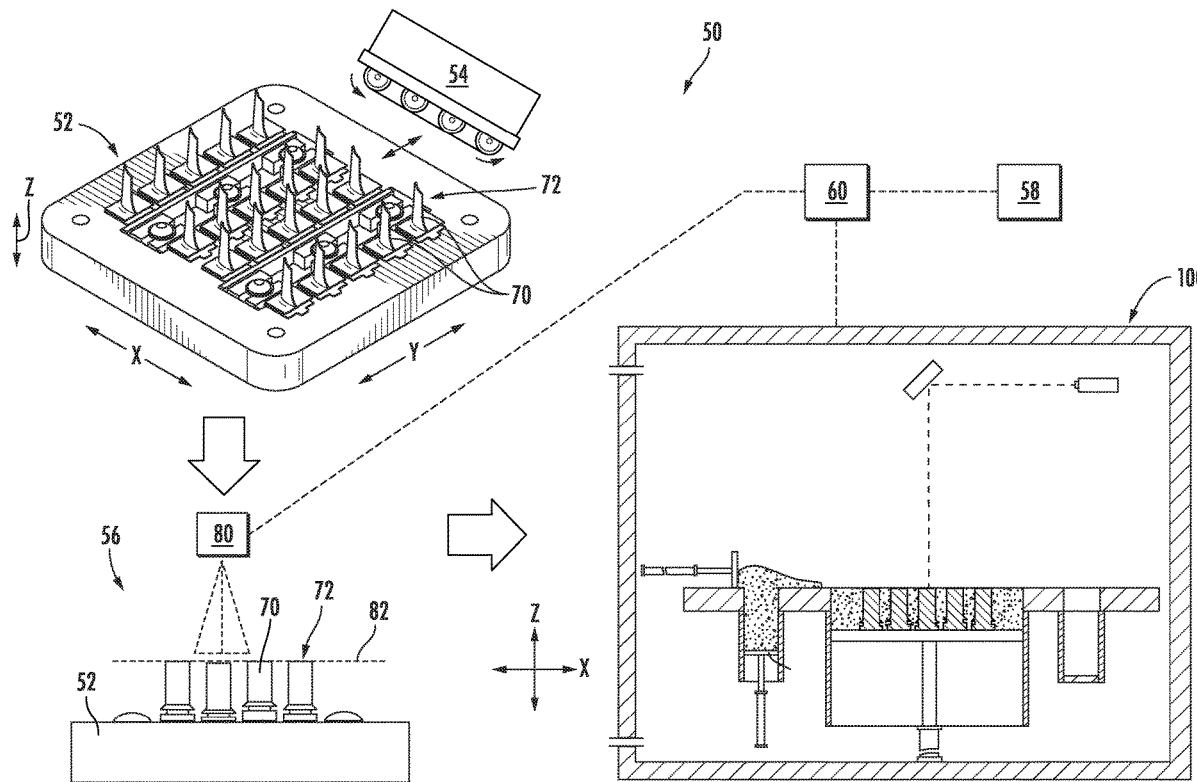
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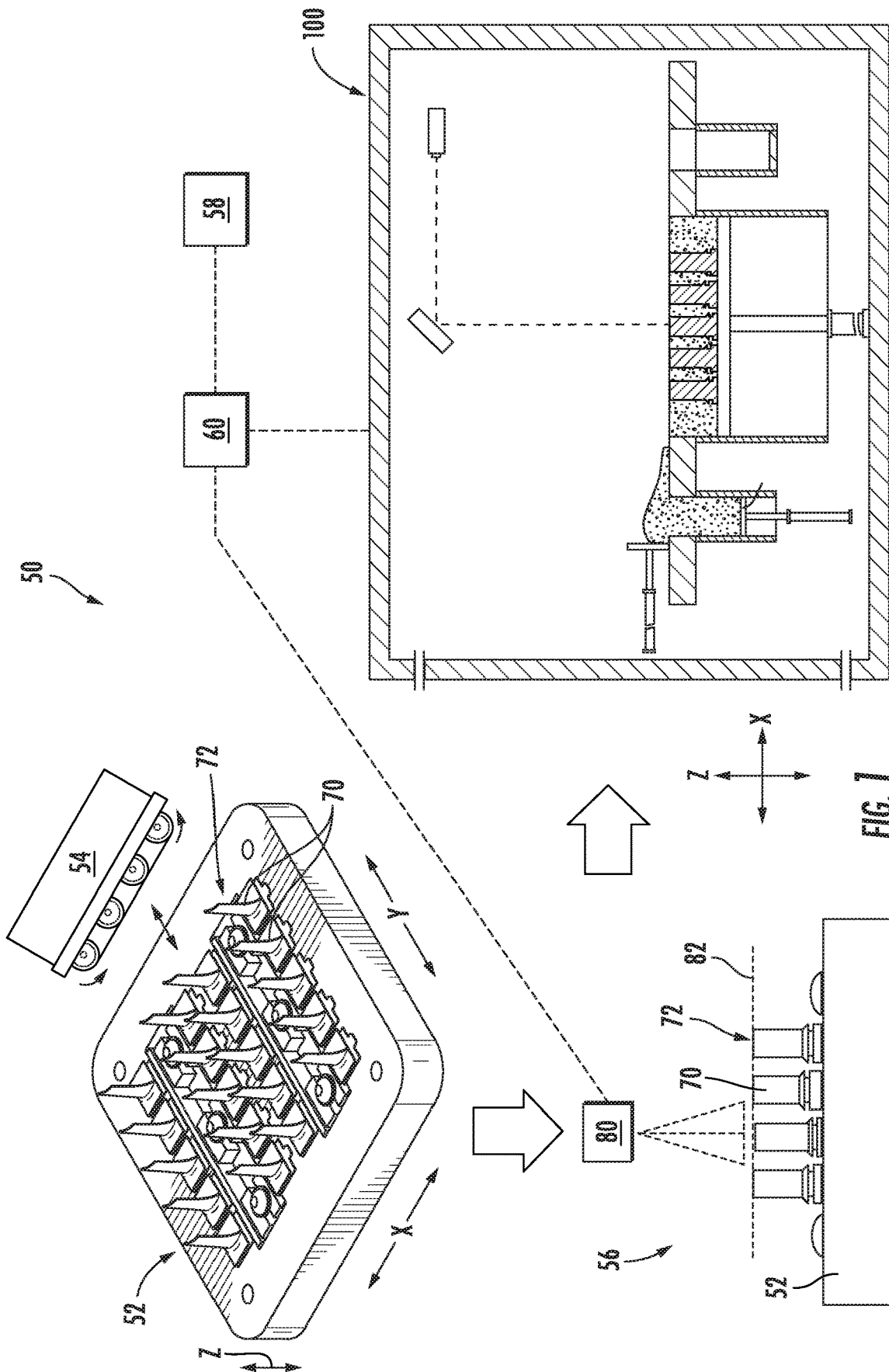
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(57) **ABSTRACT**

A tooling assembly for mounting a plurality of components, such as compressor blades, in a powder bed additive manufacturing machine to facilitate a repair process is provided. The tooling assembly includes component fixtures configured for receiving each of the compressor blades, a mounting plate for receiving the component fixtures, and a complementary fixture defining a plurality of voids within which the compressor blades are received when the complementary fixture is mounted to the mounting plate such that less powder is required to fill the powder bed.





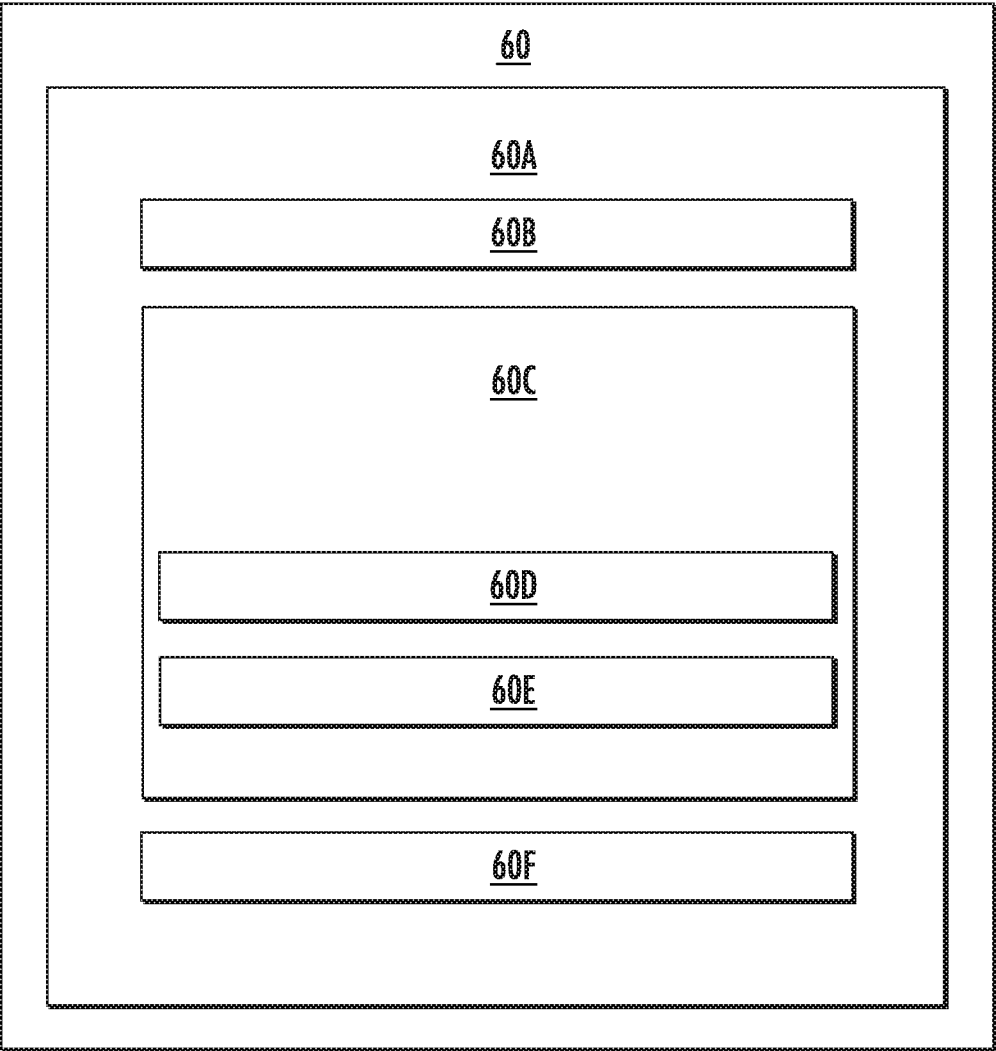


FIG. 2

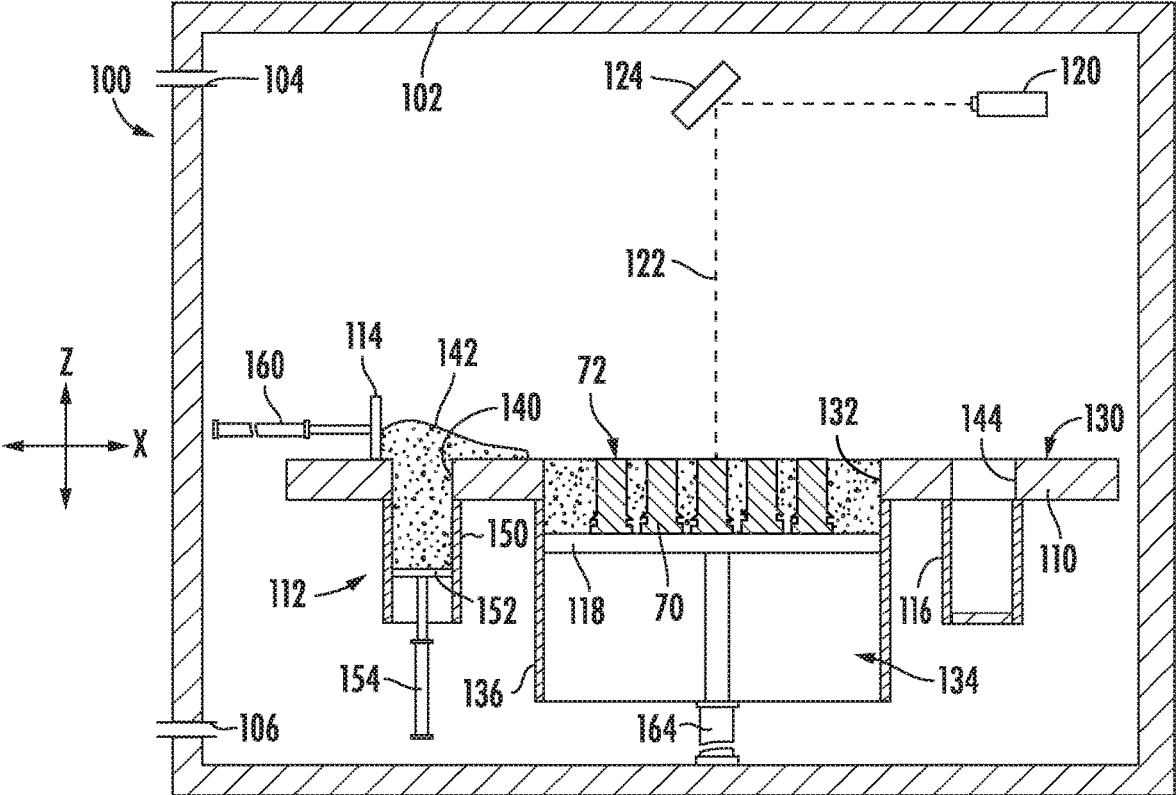


FIG. 3

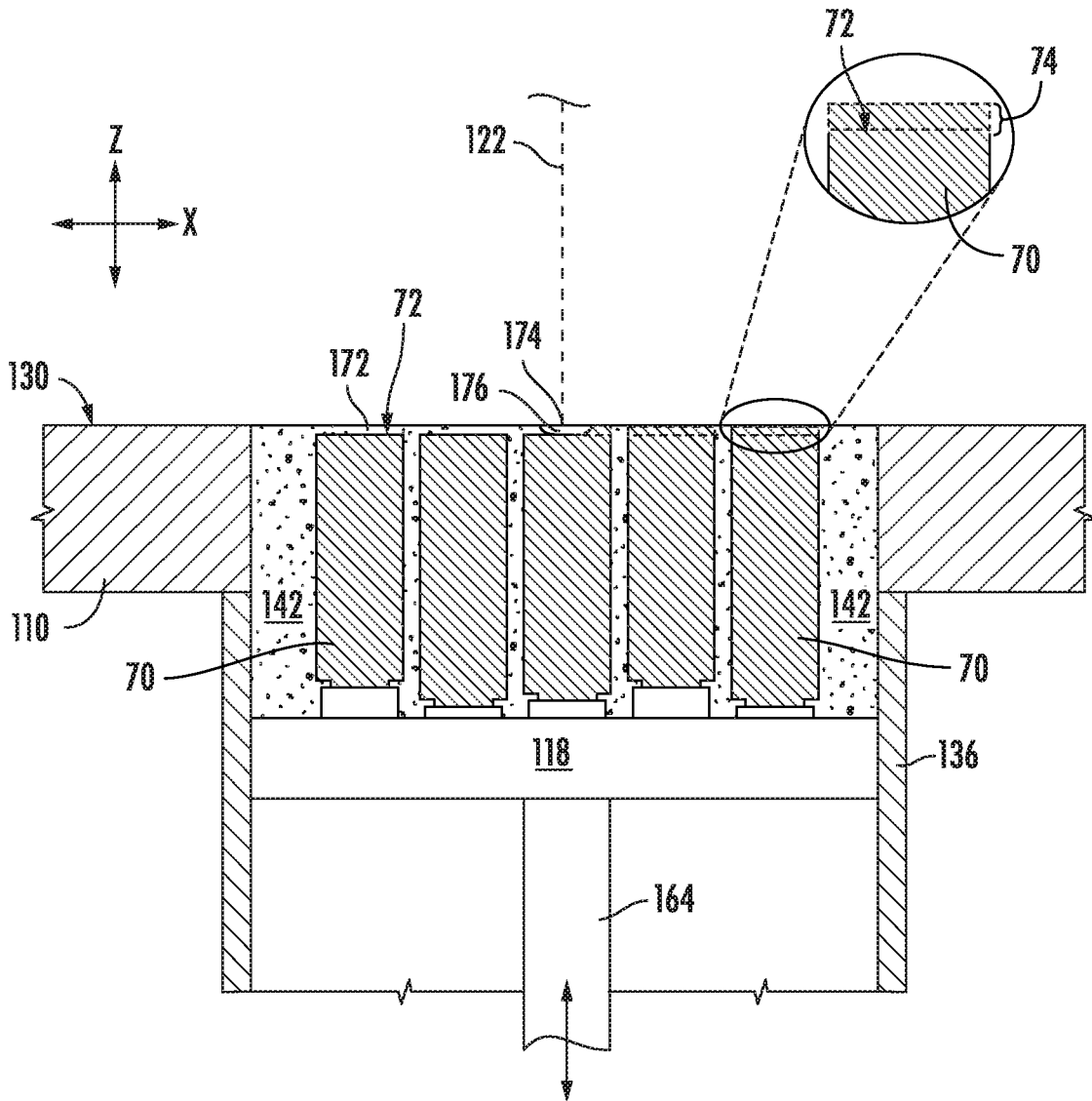


FIG. 4

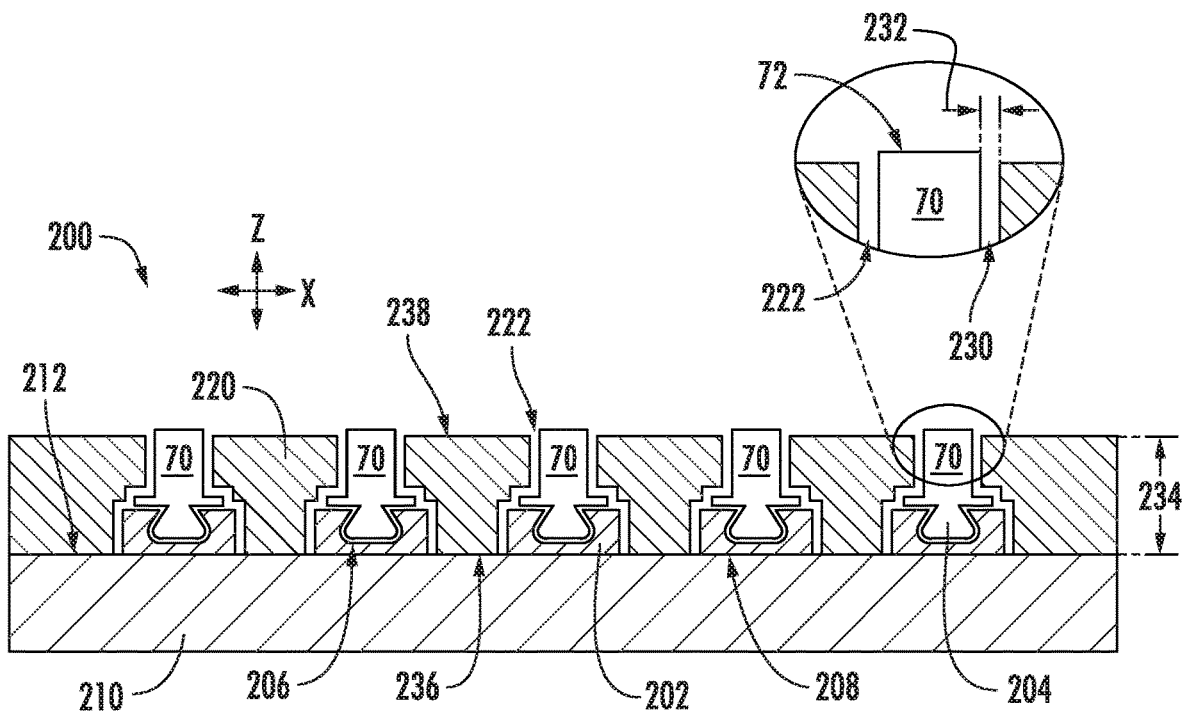


FIG. 5

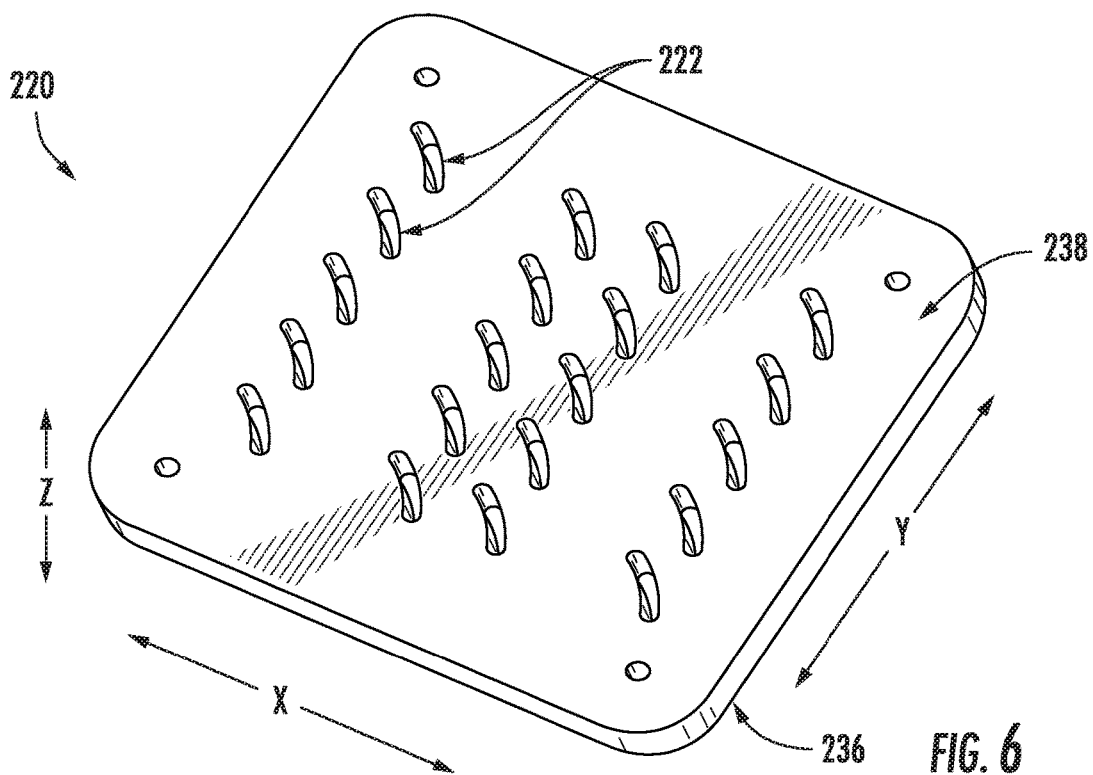


FIG. 6

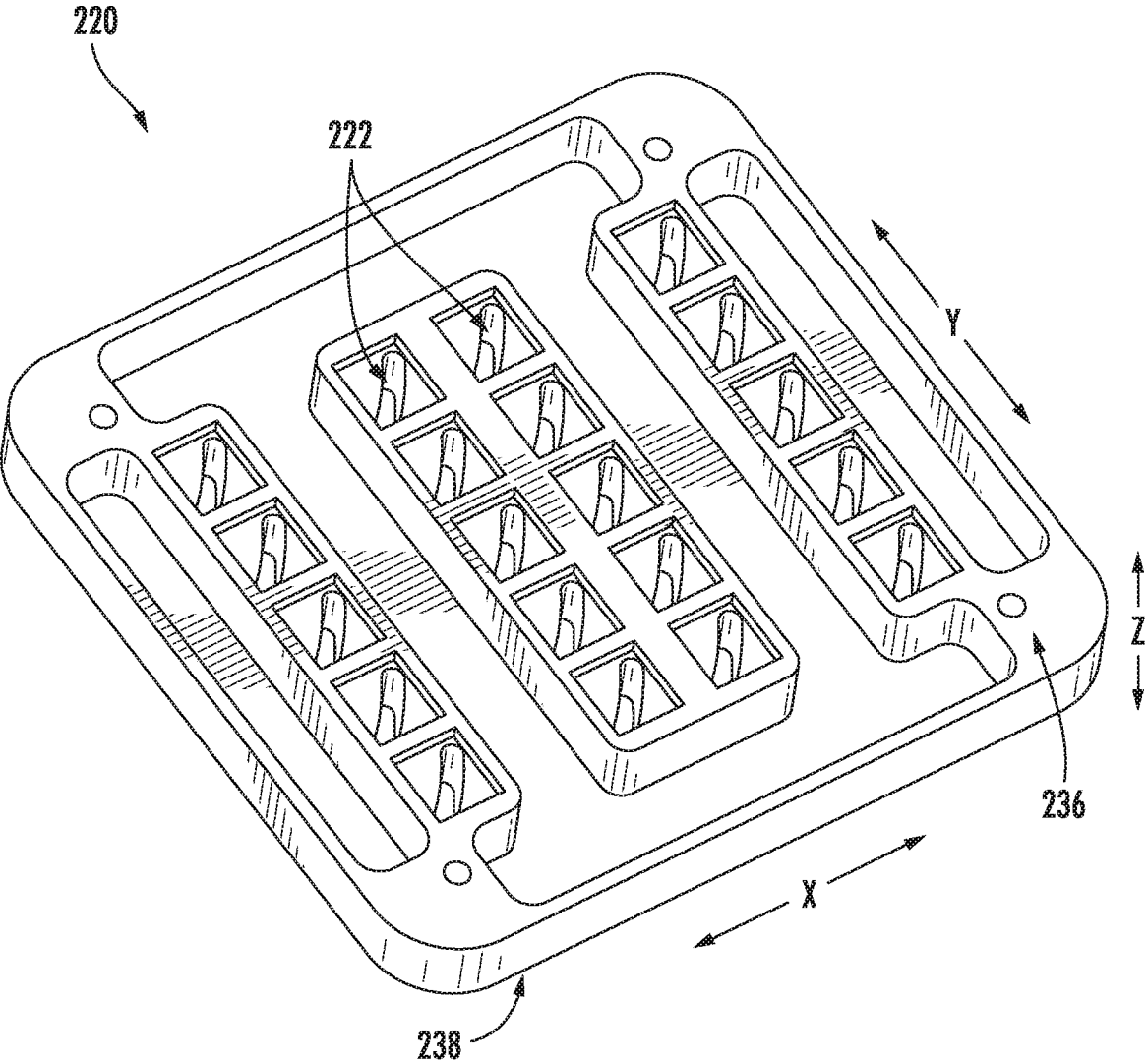


FIG. 7

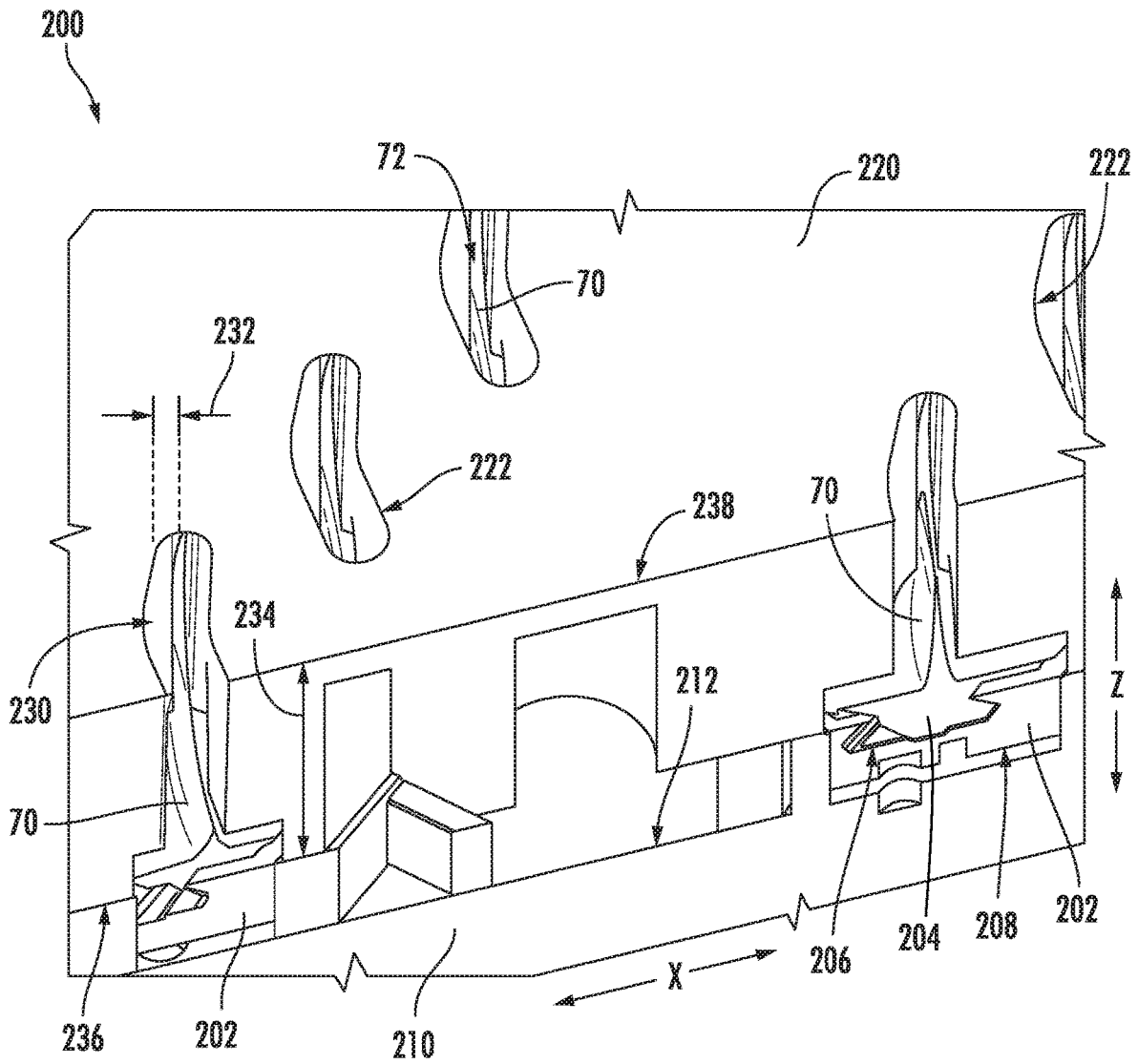


FIG. 8

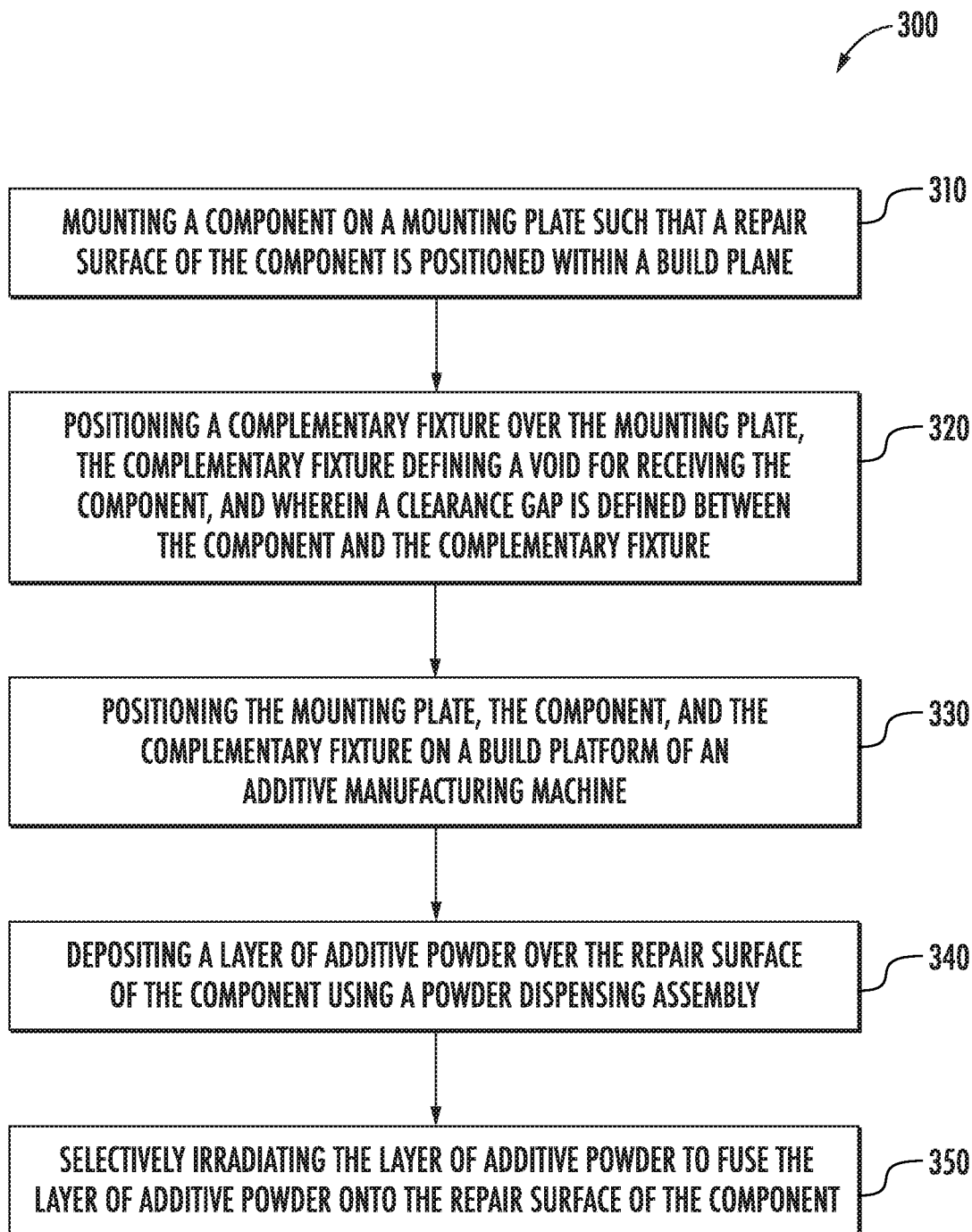


FIG. 9

TOOLING ASSEMBLY FOR DECREASING POWDER USAGE IN A POWDER BED ADDITIVE MANUFACTURING PROCESS

FIELD

[0001] The present subject matter relates generally to additive manufacturing machines, and more particularly to tooling assemblies for decreasing powder usage in a powder bed additive manufacturing process.

BACKGROUND

[0002] Machine or device components frequently experience damage, wear, and/or degradation throughout their service life. For example, serviced compressor blades of a gas turbine engine show erosion, defects, and/or cracks after long term use. Specifically, for example, such blades are subject to significant stresses which inevitably cause blades to wear over time, particularly near the tip of the blade. For example, blade tips are susceptible to wear or damage from friction or rubbing between the blade tips and shrouds, from chemical degradation or oxidation from hot gasses, from fatigue caused by cyclic loading and unloading, from diffusion creep of crystalline lattices, etc.

[0003] Notably, worn or damaged blades may result in machine failure or performance degradation if not corrected. Specifically, such blades may cause a turbomachine to exhibit reduced operating efficiency as gaps between blade tips and turbine shrouds may allow gasses to leak through the turbine stages without being converted to mechanical energy. When efficiency drops below specified levels, the turbomachine is typically removed from service for overhaul and refurbishment. Moreover, weakened blades may result in complete fractures and catastrophic failure of the engine.

[0004] As a result, compressor blades for a gas turbine engine are typically the target of frequent inspections, repairs, or replacements. It is frequently very expensive to replace such blades altogether, however, some can be repaired for extended lifetime at relatively low cost (as compared to replacement with entirely new blades). Nevertheless, existing repair processes tend to be labor intensive and time consuming.

[0005] For example, a traditional compressor blade tip repair process uses a welding/cladding technique where repair materials are supplied, in either powder or wire form, to the blade tips. The repair materials are melted by focused power source (e.g., laser, e-beam, plasma arc, etc.) and bonded to blade tips. However, blades repaired with such welding/cladding technique need tedious post-processing to achieve the target geometry and surface finish. Specifically, due to the bulky feature size of the welding/cladding repair joint, the repaired blades require heavy machining to remove the extra materials on the tip, and further require a secondary polishing process to achieve a target surface finish. Notably, such a process is performed on a single blade at a time, is very labor intensive and tedious, and results in very large overall labor costs for a single repair.

[0006] Alternatively, other direct-energy-deposition (DED) methods may be used for blade repair, e.g., such as cold spray, which directs high-speed metal powders to bombard the target or base component such that the powders deform and deposit on the base component. However, none of these DED methods are suitable for batch processing or

for repairing a large number of components in a time efficient manner, thus providing little or no business value.

[0007] Accordingly, novel systems and methods have been developed and are presented herein for repairing or rebuilding worn compressor blades (or any other components) using a powder bed additive manufacturing process. Specifically, such a repair process generally includes removing the worn portion of each of a plurality of compressor blades, positioning the plurality of compressor blades on a build platform of an additive manufacturing machine, determining the precise location of each blade tip, and printing repair segments directly onto the blade tips, layer by layer, until the compressor blades reach their original dimensions or another suitable target size and shape.

[0008] One of the key challenges with such a novel additive manufacturing DMLM repair procedures described herein relates to loading, unloading, and handling additive powder which is used to fill the powder bed. In this regard, to perform a repair process on the tip of a blade, the powder bed must first be loaded with additive powder to the height of the blade tips. Such a process generally includes manually loading the additive powder, which is time-consuming and can also be costly especially for components with large dimensions in the build orientation, e.g., the height of the blades. Moreover, any unpacked additive powder might collapse during printing, resulting in failure of recoating. In addition, filling the entire volume of the powder bed which is not filled by components to be repaired can require a large volume of powder, which must be added prior to printing, removed after printing, and filtered or screened prior to reuse during a subsequent additive manufacturing process.

[0009] Accordingly, a system and method for repairing components using an additive manufacturing machine would be useful. More particularly, an additive manufacturing machine including a tooling assembly for facilitating an additive repair process while decreasing additive powder usage would be particularly beneficial.

BRIEF DESCRIPTION

[0010] Aspects and advantages of the invention will be set forth in part in the following description, or may be obvious from the description, or may be learned through practice of the invention.

[0011] In one exemplary embodiment of the present disclosure, a tooling assembly for supporting a component during a powder bed additive manufacturing process is provided. The tooling assembly includes a mounting plate configured for receiving the component such that a repair surface of the component is positioned within a build plane and a complementary fixture defining a void corresponding to the component such that positioning the complementary fixture over the mounting plate positions the component within the void.

[0012] In another exemplary aspect of the present disclosure, a method of repairing a component using an additive manufacturing machine is provided. The method includes mounting the component on a mounting plate such that a repair surface of the component is positioned within a build plane and positioning a complementary fixture over the mounting plate, the complementary fixture defining a void for receiving the component, and wherein a clearance gap is defined between the component and the complementary fixture.

[0013] These and other features, aspects, and advantages of the present invention will become better understood with reference to the following description and appended claims. The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] A full and enabling disclosure of the present invention, including the best mode thereof, directed to one of ordinary skill in the art, is set forth in the specification, which makes reference to the appended figures.

[0015] FIG. 1 shows a schematic representation of an additive repair system that may be used for repairing or rebuilding components according to an exemplary embodiment of the present subject matter.

[0016] FIG. 2 depicts certain components of a controller according to example embodiments of the present subject matter.

[0017] FIG. 3 shows a schematic view of an additive manufacturing machine that may be used as part of the exemplary additive manufacturing system of FIG. 1 according to an exemplary embodiment of the present subject matter.

[0018] FIG. 4 shows a close-up schematic view of a build platform of the exemplary additive manufacturing machine of FIG. 3 according to an exemplary embodiment of the present subject matter.

[0019] FIG. 5 is a schematic cross sectional view of a tooling assembly for supporting a component during a powder bed additive manufacturing process according to an exemplary embodiment of the present subject matter.

[0020] FIG. 6 is a top perspective view of the exemplary tooling assembly of FIG. 5 according to an exemplary embodiment of the present subject matter.

[0021] FIG. 7 is a bottom perspective view of the exemplary tooling assembly of FIG. 5 according to an exemplary embodiment of the present subject matter.

[0022] FIG. 8 is a perspective cross sectional view of the exemplary tooling assembly of FIG. 5 positioned over a plurality of components according to an exemplary embodiment of the present subject matter.

[0023] FIG. 9 is a method of mounting a plurality of components in a powder bed additive manufacturing machine according to an exemplary embodiment of the present subject matter.

[0024] Repeat use of reference characters in the present specification and drawings is intended to represent the same or analogous features or elements of the present invention.

DETAILED DESCRIPTION

[0025] Reference now will be made in detail to embodiments of the invention, one or more examples of which are illustrated in the accompanying drawings. Each example is provided by way of explanation of the invention, not limitation of the invention. In fact, it will be apparent to those skilled in the art that various configurations, modifications, and variations can be made in the present invention without departing from the scope or spirit of the invention. For instance, features illustrated or described as part of one embodiment can be used with another embodiment to yield a still further embodiment. Thus, it is intended that the

present invention covers such modifications and variations as come within the scope of the appended claims and their equivalents.

[0026] As used herein, the terms “first,” “second,” and “third” may be used interchangeably to distinguish one component from another and are not intended to signify location or importance of the individual components. In addition, the terms “upstream” and “downstream” refer to the relative direction with respect to the motion of an object or a flow of fluid. For example, “upstream” refers to the direction from which the object has moved or fluid has flowed, and “downstream” refers to the direction to which the object is moving or the fluid is flowing. Furthermore, as used herein, terms of approximation, such as “approximately,” “substantially,” or “about,” refer to being within a ten percent margin of error.

[0027] Aspects of the present subject matter are directed to a system and method for repairing one or more components using an additive manufacturing process. The method includes securing the components in a tooling assembly such that a repair surface of each component is positioned within a single build plane, determining a repair toolpath corresponding to the repair surface of each component using a vision system, depositing a layer of additive powder over the repair surface of each component using a powder dispensing assembly, and selectively irradiating the layer of additive powder along the repair toolpath to fuse the layer of additive powder onto the repair surface of each component.

[0028] Specifically, aspects of the present subject matter provide a tooling assembly for mounting a plurality of components, such as compressor blades, in a powder bed additive manufacturing machine to facilitate such a repair process. The tooling assembly includes component fixtures configured for receiving each of the compressor blades, a mounting plate for receiving the component fixtures, and a complementary fixture defining a plurality of voids within which the compressor blades are received when the complementary fixture is mounted to the mounting plate such that less powder is required to fill the powder bed.

[0029] As described in detail below, exemplary embodiments of the present subject matter involve the use of additive manufacturing machines or methods. As used herein, the terms “additively manufactured” or “additive manufacturing techniques or processes” refer generally to manufacturing processes wherein successive layers of material(s) are provided on each other to “build-up,” layer-by-layer, a three-dimensional component. The successive layers generally fuse together to form a monolithic component which may have a variety of integral sub-components.

[0030] Although additive manufacturing technology is described herein as enabling fabrication of complex objects by building objects point-by-point, layer-by-layer, typically in a vertical direction, other methods of fabrication are possible and within the scope of the present subject matter. For example, although the discussion herein refers to the addition of material to form successive layers, one skilled in the art will appreciate that the methods and structures disclosed herein may be practiced with any additive manufacturing technique or manufacturing technology. For example, embodiments of the present invention may use layer-additive processes, layer-subtractive processes, or hybrid processes.

[0031] Suitable additive manufacturing techniques in accordance with the present disclosure include, for example,

Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), 3D printing such as by inkjets and laserjets, Stereolithography (SLA), Direct Selective Laser Sintering (DSLS), Electron Beam Sintering (EBS), Electron Beam Melting (EBM), Laser Engineered Net Shaping (LENS), Laser Net Shape Manufacturing (LNSM), Direct Metal Deposition (DMD), Digital Light Processing (DLP), Direct Selective Laser Melting (DSLML), Selective Laser Melting (SLM), Direct Metal Laser Melting (DMLM), and other known processes.

[0032] In addition to using a direct metal laser sintering (DMLS) or direct metal laser melting (DMLM) process where an energy source is used to selectively sinter or melt portions of a layer of powder, it should be appreciated that according to alternative embodiments, the additive manufacturing process may be a “binder jetting” process. In this regard, binder jetting involves successively depositing layers of additive powder in a similar manner as described above. However, instead of using an energy source to generate an energy beam to selectively melt or fuse the additive powders, binder jetting involves selectively depositing a liquid binding agent onto each layer of powder. The liquid binding agent may be, for example, a photo-curable polymer or another liquid bonding agent. Other suitable additive manufacturing methods and variants are intended to be within the scope of the present subject matter.

[0033] The additive manufacturing processes described herein may be used for forming components using any suitable material. For example, the material may be plastic, metal, concrete, ceramic, polymer, epoxy, photopolymer resin, or any other suitable material that may be in solid, liquid, powder, sheet material, wire, or any other suitable form. More specifically, according to exemplary embodiments of the present subject matter, the additively manufactured components described herein may be formed in part, in whole, or in some combination of materials including but not limited to pure metals, nickel alloys, chrome alloys, titanium, titanium alloys, magnesium, magnesium alloys, aluminum, aluminum alloys, iron, iron alloys, stainless steel, and nickel or cobalt based superalloys (e.g., those available under the name Inconel® available from Special Metals Corporation). These materials are examples of materials suitable for use in the additive manufacturing processes described herein, and may be generally referred to as “additive materials.”

[0034] In addition, one skilled in the art will appreciate that a variety of materials and methods for bonding those materials may be used and are contemplated as within the scope of the present disclosure. As used herein, references to “fusing” may refer to any suitable process for creating a bonded layer of any of the above materials. For example, if an object is made from polymer, fusing may refer to creating a thermoset bond between polymer materials. If the object is epoxy, the bond may be formed by a crosslinking process. If the material is ceramic, the bond may be formed by a sintering process. If the material is powdered metal, the bond may be formed by a melting or sintering process. One skilled in the art will appreciate that other methods of fusing materials to make a component by additive manufacturing are possible, and the presently disclosed subject matter may be practiced with those methods.

[0035] In addition, the additive manufacturing process disclosed herein allows a single component to be formed from multiple materials. Thus, the components described

herein may be formed from any suitable mixtures of the above materials. For example, a component may include multiple layers, segments, or parts that are formed using different materials, processes, and/or on different additive manufacturing machines. In this manner, components may be constructed which have different materials and material properties for meeting the demands of any particular application. In addition, although the components described herein are constructed entirely by additive manufacturing processes, it should be appreciated that in alternate embodiments, all or a portion of these components may be formed via casting, machining, and/or any other suitable manufacturing process. Indeed, any suitable combination of materials and manufacturing methods may be used to form these components.

[0036] An exemplary additive manufacturing process will now be described. Additive manufacturing processes fabricate components using three-dimensional (3D) information, for example a three-dimensional computer model, of the component. Accordingly, a three-dimensional design model of the component may be defined prior to manufacturing. In this regard, a model or prototype of the component may be scanned to determine the three-dimensional information of the component. As another example, a model of the component may be constructed using a suitable computer aided design (CAD) program to define the three-dimensional design model of the component.

[0037] The design model may include 3D numeric coordinates of the entire configuration of the component including both external and internal surfaces of the component. For example, the design model may define the body, the surface, and/or internal passageways such as openings, support structures, etc. In one exemplary embodiment, the three-dimensional design model is converted into a plurality of slices or segments, e.g., along a central (e.g., vertical) axis of the component or any other suitable axis. Each slice may define a thin cross section of the component for a predetermined height of the slice. The plurality of successive cross-sectional slices together form the 3D component. The component is then “built-up” slice-by-slice, or layer-by-layer, until finished.

[0038] In this manner, the components described herein may be fabricated using the additive process, or more specifically each layer is successively formed, e.g., by fusing or polymerizing a plastic using laser energy or heat or by sintering or melting metal powder. For example, a particular type of additive manufacturing process may use an energy beam, for example, an electron beam or electromagnetic radiation such as a laser beam, to sinter or melt a powder material. Any suitable laser and laser parameters may be used, including considerations with respect to power, laser beam spot size, and scanning velocity. The build material may be formed by any suitable powder or material selected for enhanced strength, durability, and useful life, particularly at high temperatures.

[0039] Each successive layer may be, for example, between about 10 μm and 200 μm , although the thickness may be selected based on any number of parameters and may be any suitable size according to alternative embodiments. Therefore, utilizing the additive formation methods described above, the components described herein may have cross sections as thin as one thickness of an associated powder layer, e.g., 10 μm , utilized during the additive formation process.

[0040] In addition, utilizing an additive process, the surface finish and features of the components may vary as need depending on the application. For example, the surface finish may be adjusted (e.g., made smoother or rougher) by selecting appropriate laser scan parameters (e.g., laser power, scan speed, laser focal spot size, etc.) during the additive process, especially in the periphery of a cross-sectional layer which corresponds to the part surface. For example, a rougher finish may be achieved by increasing laser scan speed or decreasing the size of the melt pool formed, and a smoother finish may be achieved by decreasing laser scan speed or increasing the size of the melt pool formed. The scanning pattern and/or laser power can also be changed to change the surface finish in a selected area.

[0041] After fabrication of the component is complete, various post-processing procedures may be applied to the component. For example, post processing procedures may include removal of excess powder by, for example, blowing or vacuuming. Other post processing procedures may include a stress relief process. Additionally, thermal, mechanical, and/or chemical post processing procedures can be used to finish the part to achieve a desired strength, surface finish, and other component properties or features.

[0042] Notably, in exemplary embodiments, several aspects and features of the present subject matter were previously not possible due to manufacturing restraints. However, the present inventors have advantageously utilized current advances in additive manufacturing techniques to improve various components and the method of additively manufacturing such components. While the present disclosure is not limited to the use of additive manufacturing to form these components generally, additive manufacturing does provide a variety of manufacturing advantages, including ease of manufacturing, reduced cost, greater accuracy, etc.

[0043] Also, the additive manufacturing methods described above enable much more complex and intricate shapes and contours of the components described herein to be formed with a very high level of precision. For example, such components may include thin additively manufactured layers, cross sectional features, and component contours. In addition, the additive manufacturing process enables the manufacture of a single component having different materials such that different portions of the component may exhibit different performance characteristics. The successive, additive nature of the manufacturing process enables the construction of these novel features. As a result, components formed using the methods described herein may exhibit improved performance and reliability.

[0044] Referring now to FIG. 1, an exemplary additive repair system 50 will be described according to an exemplary embodiment of the present subject matter. As illustrated, additive repair system 50 generally includes a tooling fixture or assembly 52, a material removal assembly 54, a vision system 56, a user interface panel 58, and an additive manufacturing machine or system 100. Furthermore, a system controller 60 may be operably coupled with some or all parts of additive repair system 50 for facilitating system operation. For example, system controller 60 may be operably coupled to user interface panel 58 to permit operator communication with additive repair system 50, e.g., to input commands, upload printing toolpaths or CAD models, initiating operating cycles, etc. Controller 60 may further be in

communication with vision system 56 for receiving imaging data and with AM machine 100 for performing a printing process.

[0045] According to exemplary embodiments, tooling assembly 52 is generally configured for supporting a plurality of components in a desired position and orientation. According to exemplary embodiments, tooling assembly 52 supports 20 high pressure compressor blades 70 during an additive manufacturing repair process. Specifically, the additive manufacturing process may be a powder bed fusion process (e.g., a DMLM or DMLS process as described above). Although the repaired components are illustrated herein as compressor blades 70 of a gas turbine engine, it should be appreciated that any other suitable component may be repaired, such as turbine blades, other airfoils, or components from other machines. In order to achieve proper recoating and to facilitate the printing process, it may be desirable to position all blades 70 in the same orientation and at the same height such that a repair surface 72 of each blade is in a single build plane. Tooling assembly 52 is a fixture intended to secure blades 70 in such desired position and orientation.

[0046] Material removal assembly 54 may include a machine or device configured for grinding, machining, brushing, etching, polishing, wire electrical discharge machining (EDM), cutting, or otherwise substantively modifying a component, e.g., by subtractive modification or material removal. For example, material removal assembly 54 may include a belt grinder, a disc grinder, or any other grinding or abrasive mechanism. According to an exemplary embodiment, material removal assembly 54 may be configured for removing material from a tip of each blade 70 to obtain a desirable repair surface 72. For example, as explained briefly above, material removal assembly 54 may remove at least a portion of blades 70 that has been worn or damaged, e.g., which may include microcracks, pits, abrasions, defects, foreign material, depositions, imperfections, and the like. According to an exemplary embodiment, each blade 70 is prepared using material removal assembly 54 to achieve the desired repair surface 72, after which the blades 70 are all mounted in tooling assembly 52 and leveled appropriately. However, according to alternative embodiments, material removal assembly 54 may grind each blade 70 as it is fixed in position in tooling assembly 52.

[0047] After the blades are prepared, vision system 56 may be used to obtain an image or digital representation of the precise position and coordinates of each blade 70 positioned in tooling assembly 52. In this regard, according to exemplary embodiments, vision system 56 may include any suitable camera or cameras 80, scanners, imaging devices, or other machine vision device that may be operably configured to obtain image data that includes a digital representation of one or more fields of view. Such a digital representation may sometimes be referred to as a digital image or an image; however, it will be appreciated that the present disclosure may be practiced without rendering such a digital representation in human-visible form. Nevertheless, in some embodiments, a human-visible image corresponding to a field of view may be displayed on the user interface 58 based at least in part on such a digital representation of one or more fields of view.

[0048] Vision system 56 allows the additive repair system 50 to obtain information pertaining to one or more blades 70 onto which one or more repair segments 74 (see FIG. 4) may

be respectively additively printed. In particular, the vision system **56** allows the one or more blades **70** to be located and defined so that the additive manufacturing machine **100** may be instructed to print one or more repair segments **74** on a corresponding one or more blades **70** with suitably high accuracy and precision. According to an exemplary embodiment, the one or more blades **70** may be secured to tooling assembly **52**, a mounting plate, a build platform, or any other fixture with repair surface **72** of the respective blades **70** aligned to a single build plane **82**.

[0049] The one or more cameras **80** of the vision system **56** may be configured to obtain two-dimensional or three-dimensional image data, including a two-dimensional digital representation of a field of view and/or a three-dimensional digital representation of a field of view. Alignment of the repair surface **72** of the blades **70** with the build plane **82** allows the one or more cameras **80** to obtain higher quality images. For example, the one or more cameras **80** may have a focal length adjusted or adjustable to the build plane **82**. With the repair surface **72** of one or more blades **70** aligned to the build plane **82**, the one or more cameras may readily obtain digital images of the repair surface **72**. The one or more cameras **80** may include a field of view that encompasses all or a portion of the one or more blades **70** secured to the tooling assembly **52**. For example, a single field of view may be wide enough to encompass a plurality of components, such as each of the plurality of blades **70** secured to tooling assembly **52**. Alternatively, a field of view may more narrowly focus on an individual blade **70** such that digital representations of respective blades **70** are obtained separately. It will be appreciated that separately obtained digital images may be stitched together to obtain a digital representation of a plurality of components or blades **70**. In some embodiments, the camera **80** may include a collimated lens configured to provide a flat focal plane, such that blades **70** or portions thereof located towards the periphery of the field of view are not distorted. Additionally, or in the alternative, the vision system **56** may utilize a distortion correction algorithm to address any such distortion.

[0050] Image data obtained by the vision system **56**, including a digital representation of one or more blades **70** may be transmitted to a control system, such as controller **60**. Controller **60** may be configured to determine a repair surface **72** of each of a plurality of blades **70** from one or more digital representations of one or more fields of view having been captured by the vision system **56**, and then determine one or more coordinates of the repair surface **72** of respective ones of the plurality of blades **70**. Based on the one or more digital representations, controller **60** may generate one or more print commands (e.g., corresponding to one or more repair toolpaths, e.g., the path of a laser focal point), which may be transmitted to an additive manufacturing machine **100** such that the additive manufacturing machine **100** may additively print a plurality of repair segments **74** on respective ones of the plurality of blades **70**. The one or more print commands may be configured to additively print a plurality of repair segments **74** with each respective one of the plurality of repair segments **74** being located on the repair surface **72** of a corresponding blade **70**.

[0051] Each of the components and subsystems of additive repair system **50** are described herein in the context of an additive blade repair process. However, it should be appreciated that aspects of the present subject matter may be used

to repair or rebuild any suitable components. The present subject matter is not intended to be limited to the specific repair process described. In addition, FIG. 1 illustrates each of the systems as being distinct or separate from each other and implies the process steps should be performed in a particular order, however, it should be appreciated that these subsystems may be integrated into a single machine, process steps may be swapped, and other changes to the build process may be implemented while remaining within the scope of the present subject matter.

[0052] For example, vision system **56** and additive manufacturing machine **100** may be provided as a single, integrated unit or as separate stand-alone units. In addition, controller **60** may include one or more control systems. For example, a single controller **60** may be operably configured to control operations of the vision system **56** and the additive manufacturing machine **100**, or separate controllers **60** may be operably configured to respectively control the vision system **56** and the additive manufacturing machine **100**.

[0053] Operation of additive repair system **50**, vision system **56**, and AM machine **100** may be controlled by electromechanical switches or by a processing device or controller **60** (see, e.g., FIGS. 1 and 2). According to exemplary embodiments, controller **60** may be operatively coupled to user interface panel **58** for user manipulation, e.g., to control the operation of various components of AM machine **100** or system **50**. In this regard, controller **60** may operably couple all systems and subsystems within additive repair system **50** to permit communication and data transfer therebetween. In this manner, controller **60** may be generally configured for operating additive repair system **50** or performing one or more of the methods described herein.

[0054] FIG. 2 depicts certain components of controller **60** according to example embodiments of the present disclosure. Controller **60** can include one or more computing device(s) **60A** which may be used to implement methods as described herein. Computing device(s) **60A** can include one or more processor(s) **60B** and one or more memory device(s) **60C**. The one or more processor(s) **60B** can include any suitable processing device, such as a microprocessor, micro-controller, integrated circuit, an application specific integrated circuit (ASIC), a digital signal processor (DSP), a field-programmable gate array (FPGA), logic device, one or more central processing units (CPUs), graphics processing units (GPUs) (e.g., dedicated to efficiently rendering images), processing units performing other specialized calculations, etc. The memory device(s) **60C** can include one or more non-transitory computer-readable storage medium(s), such as RAM, ROM, EEPROM, EPROM, flash memory devices, magnetic disks, etc., and/or combinations thereof.

[0055] The memory device(s) **60C** can include one or more computer-readable media and can store information accessible by the one or more processor(s) **60B**, including instructions **60D** that can be executed by the one or more processor(s) **60B**. For instance, the memory device(s) **60C** can store instructions **60D** for running one or more software applications, displaying a user interface, receiving user input, processing user input, etc. In some implementations, the instructions **60D** can be executed by the one or more processor(s) **60B** to cause the one or more processor(s) **60B** to perform operations, e.g., such as one or more portions of methods described herein. The instructions **60D** can be software written in any suitable programming language or can be implemented in hardware. Additionally, and/or alter-

natively, the instructions 60D can be executed in logically and/or virtually separate threads on processor(s) 60B.

[0056] The one or more memory device(s) 60C can also store data 60E that can be retrieved, manipulated, created, or stored by the one or more processor(s) 60B. The data 60E can include, for instance, data to facilitate performance of methods described herein. The data 60E can be stored in one or more database(s). The one or more database(s) can be connected to controller 60 by a high bandwidth LAN or WAN, or can also be connected to controller through one or more network(s) (not shown). The one or more database(s) can be split up so that they are located in multiple locales. In some implementations, the data 60E can be received from another device.

[0057] The computing device(s) 60A can also include a communication module or interface 60F used to communicate with one or more other component(s) of controller 60 or additive manufacturing machine 100 over the network(s). The communication interface 60F can include any suitable components for interfacing with one or more network(s), including for example, transmitters, receivers, ports, controllers, antennas, or other suitable components.

[0058] Referring now to FIG. 3, an exemplary laser powder bed fusion system, such as a DMLS or DMLM system 100, will be described according to an exemplary embodiment. Specifically, AM system 100 is described herein as being used to build or repair blades 70. It should be appreciated that blades 70 are only an exemplary component to be built or repaired and are used primarily to facilitate description of the operation of AM machine 100. The present subject matter is not intended to be limited in this regard, but instead AM machine 100 may be used for printing repair segments on any suitable plurality of components.

[0059] As illustrated, AM system 100 generally defines a vertical direction V or Z-direction, a lateral direction L or X-direction, and a transverse direction T or Y-direction (see FIG. 1), each of which is mutually perpendicular, such that an orthogonal coordinate system is generally defined. As illustrated, system 100 includes a fixed enclosure or build area 102 which provides a contaminant-free and controlled environment for performing an additive manufacturing process. In this regard, for example, enclosure 102 serves to isolate and protect the other components of the system 100. In addition, enclosure 102 may be provided with a flow of an appropriate shielding gas, such as nitrogen, argon, or another suitable gas or gas mixture. In this regard, enclosure 102 may define a gas inlet port 104 and a gas outlet port 106 for receiving a flow of gas to create a static pressurized volume or a dynamic flow of gas.

[0060] Enclosure 102 may generally contain some or all components of AM system 100. According to an exemplary embodiment, AM system 100 generally includes a table 110, a powder supply 112, a scraper or recoater mechanism 114, an overflow container or reservoir 116, and a build platform 118 positioned within enclosure 102. In addition, an energy source 120 generates an energy beam 122 and a beam steering apparatus 124 directs energy beam 122 to facilitate the AM process as described in more detail below. Each of these components will be described in more detail below.

[0061] According to the illustrated embodiment, table 110 is a rigid structure defining a planar build surface 130. In addition, planar build surface 130 defines a build opening 132 through which build chamber 134 may be accessed.

More specifically, according to the illustrated embodiment, build chamber 134 is defined at least in part by vertical walls 136 and build platform 118. In addition, build surface 130 defines a supply opening 140 through which additive powder 142 may be supplied from powder supply 112 and a reservoir opening 144 through which excess additive powder 142 may pass into overflow reservoir 116. Collected additive powders may optionally be treated to sieve out loose, agglomerated particles before re-use.

[0062] Powder supply 112 generally includes an additive powder supply container 150 which generally contains a volume of additive powder 142 sufficient for some or all of the additive manufacturing process for a specific part or parts. In addition, powder supply 112 includes a supply platform 152, which is a plate-like structure that is movable along the vertical direction within powder supply container 150. More specifically, a supply actuator 154 vertically supports supply platform 152 and selectively moves it up and down during the additive manufacturing process.

[0063] AM system 100 further includes recoater mechanism 114, which is a rigid, laterally-elongated structure that lies proximate build surface 130. For example, recoater mechanism 114 may be a hard scraper, a soft squeegee, or a roller. Recoater mechanism 114 is operably coupled to a recoater actuator 160 which is operable to selectively move recoater mechanism 114 along build surface 130. In addition, a platform actuator 164 is operably coupled to build platform 118 and is generally operable for moving build platform 118 along the vertical direction during the build process. Although actuators 154, 160, and 164 are illustrated as being hydraulic actuators, it should be appreciated that any other type and configuration of actuators may be used according to alternative embodiments, such as pneumatic actuators, hydraulic actuators, ball screw linear electric actuators, or any other suitable vertical support means. Other configurations are possible and within the scope of the present subject matter.

[0064] As used herein, “energy source” may be used to refer to any device or system of devices configured for directing an energy beam of suitable power and other operating characteristics towards a layer of additive powder to sinter, melt, or otherwise fuse a portion of that layer of additive powder during the build process. For example, energy source 120 may be a laser or any other suitable irradiation emission directing device or irradiation device. In this regard, an irradiation or laser source may originate photons or laser beam irradiation which is directed by the irradiation emission directing device or beam steering apparatus.

[0065] According to an exemplary embodiment, beam steering apparatus 124 includes one or more mirrors, prisms, lenses, and/or electromagnets operably coupled with suitable actuators and arranged to direct and focus energy beam 122. In this regard, for example, beam steering apparatus 124 may be a galvanometer scanner that moves or scans the focal point of the laser beam 122 emitted by energy source 120 across the build surface 130 during the laser melting and sintering processes. In this regard, energy beam 122 can be focused to a desired spot size and steered to a desired position in plane coincident with build surface 130. The galvanometer scanner in powder bed fusion technologies is typically of a fixed position but the movable mirrors/lenses contained therein allow various properties of the laser beam to be controlled and adjusted. According to exemplary

embodiments, beam steering apparatus may further include one or more of the following: optical lenses, deflectors, mirrors, beam splitters, telecentric lenses, etc.

[0066] It should be appreciated that other types of energy sources **120** may be used which may use an alternative beam steering apparatus **124**. For example, an electron beam gun or other electron source may be used to originate a beam of electrons (e.g., an “e-beam”). The e-beam may be directed by any suitable irradiation emission directing device preferably in a vacuum. When the irradiation source is an electron source, the irradiation emission directing device may be, for example, an electronic control unit which may include, for example, deflector coils, focusing coils, or similar elements. According to still other embodiments, energy source **120** may include one or more of a laser, an electron beam, a plasma arc, an electric arc, etc.

[0067] Prior to an additive manufacturing process, recoater actuator **160** may be lowered to provide a supply of powder **142** of a desired composition (for example, metallic, ceramic, and/or organic powder) into supply container **150**. In addition, platform actuator **164** may move build platform **118** to an initial high position, e.g., such that it substantially flush or coplanar with build surface **130**. Build platform **118** is then lowered below build surface **130** by a selected layer increment. The layer increment affects the speed of the additive manufacturing process and the resolution of a components or parts (e.g., blades **70**) being manufactured. As an example, the layer increment may be about 10 to 100 micrometers (0.0004 to 0.004 in.).

[0068] Additive powder is then deposited over the build platform **118** before being fused by energy source **120**. Specifically, supply actuator **154** may raise supply platform **152** to push powder through supply opening **140**, exposing it above build surface **130**. Recoater mechanism **114** may then be moved across build surface **130** by recoater actuator **160** to spread the raised additive powder **142** horizontally over build platform **118** (e.g., at the selected layer increment or thickness). Any excess additive powder **142** drops through the reservoir opening **144** into the overflow reservoir **116** as recoater mechanism **114** passes from left to right (as shown in FIG. 3). Subsequently, recoater mechanism **114** may be moved back to a starting position.

[0069] Therefore, as explained herein and illustrated in FIG. 3, recoater mechanism **114**, recoater actuator **160**, supply platform **152**, and supply actuator **154** may generally operate to successively deposit layers of additive powder **142** or other additive material to facilitate the print process. As such, these components may collectively be referred to herein as powder dispensing apparatus, system, or assembly. The leveled additive powder **142** may be referred to as a “build layer” **172** (see FIG. 4) and the exposed upper surface thereof may be referred to as build surface **130**. When build platform **118** is lowered into build chamber **134** during a build process, build chamber **134** and build platform **118** collectively surround and support a mass of additive powder **142** along with any components (e.g., blades **70**) being built. This mass of powder is generally referred to as a “powder bed,” and this specific category of additive manufacturing process may be referred to as a “powder bed process.”

[0070] During the additive manufacturing process, the directed energy source **120** is used to melt a two-dimensional cross-section or layer of the component (e.g., blades **70**) being built. More specifically, energy beam **122** is emitted from energy source **120** and beam steering apparatus

124 is used to steer the focal point **174** of energy beam **122** over the exposed powder surface in an appropriate pattern (referred to herein as a “toolpath”). A small portion of exposed layer of the additive powder **142** surrounding focal point **174**, referred to herein as a “weld pool” or “melt pool” or “heat effected zone” **176** (best seen in FIG. 4) is heated by energy beam **122** to a temperature allowing it to sinter or melt, flow, and consolidate. As an example, melt pool **176** may be on the order of 100 micrometers (0.004 in.) wide. This step may be referred to as fusing additive powder **142**. [0071] Build platform **118** is moved vertically downward by the layer increment, and another layer of additive powder **142** is applied in a similar thickness. The directed energy source **120** again emits energy beam **122** and beam steering apparatus **124** is used to steer the focal point **174** of energy beam **122** over the exposed powder surface in an appropriate pattern. The exposed layer of additive powder **142** is heated by energy beam **122** to a temperature allowing it to sinter or melt, flow, and consolidate both within the top layer and with the lower, previously-solidified layer. This cycle of moving build platform **118**, applying additive powder **142**, and then directed energy beam **122** to melt additive powder **142** is repeated until the entire component (e.g., blades **70**) is complete.

[0072] Referring now generally to FIGS. 5 through 8, a tooling assembly **200** that may be used with AM system **100** will be described according to an exemplary embodiment of the present subject matter. For example, tooling assembly **200** may replace tooling assembly **52** as described in relation to FIG. 1. Due to the similarity between tooling assembly **200**, tooling assembly **52**, and the AM system **100** in which they are configured for operating, like reference numerals will be used in FIGS. 5 through 8 to refer to like features described with respect to FIGS. 1 through 4.

[0073] Referring now specifically to FIG. 5, tooling assembly **200** will be described according to an exemplary embodiment of the present subject matter. As explained above, tooling assembly **200** is generally configured for receiving one or more components, e.g., shown here as blades **70**, and securely mounting such components for a subsequent additive manufacturing process. Specifically, tooling assembly **200** may secure each of the plurality of blades **70** in a desired position and orientation relative to AM machine **100**.

[0074] Tooling assembly **200** generally includes a component fixture **202** configured for receiving one or more blades **70**. According to the illustrated embodiment, each component fixture **202** is configured for receiving a single blade **70**. In this regard, blade **70** may define a dovetail **204** which is configured for receipt in a complementary slot **206** defined in component fixture **202**. In this regard, once blade **70** is installed into complementary slot **206** of component fixture **202**, blades **70** may not move or rotate relative to component fixture **202**. Component fixture **202** may generally be a rectangular block with a flat bottom surface **208** which may sit flush against another flat surface.

[0075] Tooling assembly **200** may further include a mounting plate **210** that is configured for receiving the plurality of component fixtures **202**. In this regard, mounting plate **210** may be a rigid plate having a flat receiving surface **212** upon which component fixtures **202** may be seated. Notably, as described briefly above, it is desirable to fix the position and orientation of blades **70** prior to an additive manufacturing process. In this regard, as used herein, the

“position” of a blade 70 may refer to the coordinates of a centroid of blade 70 in the X-Y plane. In addition, the “orientation” of a blade 70 may refer to an angular position of blade 70 about the Z-direction. In this regard, according to an exemplary embodiment, the orientation of each blade 70 may be defined according to the angular position of its chord line (not shown). In this regard, for example, two blades 70 are said to have the same “orientation” when their chord lines are parallel to each other.

[0076] According to the exemplary embodiment described herein, mounting plate 210 is configured for receiving a plurality of component fixtures 202 before being positioned at a known location on build platform 118. However, it should be appreciated that according to alternative embodiments build platform 118 may be used directly as a mounting plate 210. In this regard, for example, mounting plate 210 may be removed altogether and component fixtures 202 may be positioned, oriented, and secured where desired directly on build platform 118.

[0077] Thus, as explained above, tooling assembly 200 is generally configured for supporting a plurality of blades 70 within a powder bed of additive manufacturing machine 100. In addition, according to an exemplary embodiment, each blade 70 is mounted into a component fixture 202 and positioned on mounting plate 210 or directly on build platform 118 such that the repair surface 72 of each blade 70 is positioned within a build plane 82. In this manner, a layer of additive powder (e.g., build layer 172) may be deposited over each repair surface 72 at a desired thickness for forming a first layer of repair segments 74 (FIG. 4) on the tip of each blade 70.

[0078] Notably, however, due to the height of each blade 70 relative to a height of repair segments 74, conventional additive manufacturing processes require a substantial amount of additive powder 142. Specifically, a substantial volume of additive powder 142 must typically be provided into build chamber 134 to form a powder bed that supports the top layer of additive powder or build layer 172. As explained above, the powder loading process is typically a manual process that takes a significant amount of time and can result in recoating or print errors when pockets or voids collapse within the additive powder 142. In addition, additive manufacturing machine 100, or build platform 118 more specifically, is typically configured for only supporting a specific volume or weight of additive powder 142 during the build process, thus introducing process limitations when powder bed is filled with additive powder 142. Finally, even to the extent some unfused additive powder 142 may be reused during subsequent additive manufacturing processes, such used additive powder 142 must be carefully screened, filtered, or otherwise reconditioned prior to reuse.

[0079] As a result, according to exemplary embodiments, tooling assembly 200 may further include a complementary fixture 220 that defines one or more voids 222 which correspond to the components being repaired, e.g., blades 70. Complementary fixture 220 is mountable to mounting plate 210 or over build platform 118 such that each of the components being repaired is positioned within one of the voids 222. Specifically, according to the illustrated embodiment, complementary fixture 220 defines twenty (20) voids 222 which correspond in shape, position, and orientation with blades 70 as mounted to mounting plate 210 or build platform 118. In this regard, for example, voids 222 may have a curved cross sectional profile corresponding to an

airfoil of each blade 70, the cross sectional profile of voids 222 may vary along the height 234 of complementary fixture to correspond to the varying cross sectional profile of the corresponding airfoil, etc. It should be appreciated that according to alternative embodiments, complementary fixture 220 may define voids 222 corresponding to any other suitable component or components to facilitate an additive repair process.

[0080] Notably, in order to facilitate mounting of complementary fixture 220 prior to a build and the removal of complementary fixture 220 after a build, it may be desirable to allow some clearance between complementary fixture 220 and blades 70 when complementary fixture 220 is mounted to mounting plate 210. Specifically, tooling assembly 200 may define a clearance gap 230 between the components and complementary fixture 220 when complementary fixture 220 is positioned over mounting plate 210 or build platform 118. In this regard, voids 222 may be slightly oversized such that blades 70 slide into voids 222 during a mounting process without contacting complementary fixture 220.

[0081] In addition, clearance gap 230 may generally permit blades 70 to be surrounded by additive powders 142 during a print process such that the presence of complementary fixture 220 has little or no effect on the additive print process, the recoating process, etc. In this regard, additive powder may be loaded into clearance gap 230 to facilitate the print process without requiring a substantial amount of additive powder or powder loading time.

[0082] According to the illustrated embodiment, clearance gap 230 defines a width 232 which is substantially constant along a height 234 of complementary fixture 220. In this regard, the space between complementary fixture 220 and both blades 70 and the corresponding component fixtures 202 in which they are mounted may have a constant thickness such that the additive powder surrounding blades 70 is substantially equivalent along all sides of blades 70. For example, according to an exemplary embodiment, clearance gap 230 may be approximately 1 mm all the way around the component. In this manner, the powder loading process may be minimized while the print process and the recoating process remain unchanged relative to a conventional powder bed print process.

[0083] According to still other embodiments, clearance gap 230 may define a width 232 that increases gradually from a bottom 236 of complementary fixture 220 toward a top 238 complementary fixture 220. In this regard, for example, the width 232 of clearance gap 230 may start substantially small (e.g., less than 1 mm, 0.1 mm or smaller) or even be in contact with component fixture 202 proximate bottom 236 of complementary fixture 220. However, the width 232 may increase or taper gradually away from blades 70 proximate top 238 of complementary fixture 220. In this manner, the loading of additive powders may be further simplified, e.g., due to a larger opening at top 238 of complementary fixture 220 and the likelihood of voids or clogging of additive powder 142 is minimized due to the slanted surface or funnel shape of clearance gap 230. For example, according to an exemplary embodiment, the width 232 of clearance gap 230 proximate top 238 of complementary fixture 220 may two times, three times, or even ten times greater than width 232 proximate bottom 236 of complementary fixture 220.

[0084] Moreover, in order to facilitate the recoating process, top 238 of complementary fixture 220 is positioned at

or below the build plane **82** when positioned over mounting plate **210** or build platform **118**. Specifically, for example, blades **70** may extend above top **238** of complementary fixture **220** by approximately half a millimeter, 1 mm, or greater in order to prevent contact with a recoater mechanism **114** or to otherwise facilitate a proper recoating of additive powder or the print process.

[0085] Component fixture **202**, mounting plate **210**, and complementary fixture **220** may generally be formed from any suitable material and may have any suitable shape. According to the illustrated embodiment, these components are formed from metal such that they may be reused for multiple repair and rebuild processes. Specifically, once blades **70** have been repaired using a powder bed additive manufacturing process as described below, each blade **70** may be removed from the corresponding component fixture **202** and each of component fixture **202**, mounting plate **210**, and complementary fixture **220** may be used to mount different blades **70** in a subsequent repair process.

[0086] According to exemplary embodiment of the present subject matter, complementary fixture **220** may be designed and formed in any suitable manner for receiving blades **70**. For example, according to the illustrated embodiment, complementary fixture **220** is formed by obtaining a component CAD model of all components mounted to mounting plate **210**. In this regard, a CAD model may be generated which includes mounting plate **210** and each of blades **70** mounted to mounting plate **210** in the desired position and orientation. A fixture model, e.g., which may be used to form complementary fixture **220**, is determined by removing the component CAD model from a CAD model of a solid three-dimensional volume corresponding to the size of build chamber **134** or the powder bed. In this manner, complementary fixture **220** generally defines a mirror image or a negative image of mounting plate **210** and/or blades **70** within build chamber **134**. In other words, complementary fixture **220** corresponds substantially to the empty space or void volume within powder bed after blades **70** are fixed therein prior to an additive repair procedure.

[0087] According to exemplary embodiments, complementary fixture **220** may be formed using any suitable method and from any suitable material. For example, complementary fixture **220** may be formed from a metal, ceramic, or plastic material suitable for reuse in multiple repair procedures. In addition, complementary fixture **220** may be formed by casting, machining, or by additive manufacturing, e.g., using AM machine **100**. According to other embodiments, complementary fixture **220** may be formed from plastic, e.g. via injection molding, or may be formed in any other suitable manner or from any other suitable material.

[0088] After complementary fixture **220** is formed and positioned over build platform **118** or mounting plate **210** as desired, additive powder **142** may be loaded into powder bed and a recoating assembly, e.g., such as recoater mechanism **114**, may spread a layer of additive material (e.g., build layer **172**) over top **238** of complementary fixture **220** and the repair surfaces **72** of each component being repaired, e.g., blades **70**.

[0089] Notably, use of the additive manufacturing methods described above along with tooling assembly **200** facilitates the use of multiple different additive materials, e.g., different compositions of additive powders **142** during a single print process. In this regard, for example, the additive

powder **142** used may be a different composition than blades **70** and complementary fixture **220**. Moreover, each layer of additive material may differ from previously deposited and fused additive layers. In this regard, tooling assembly **200** may provide for precisely controlled transition locations between the two materials, e.g., between blades **70** and build layer **172**. Using the methods described herein, the additive manufacturing process may be performed in multiple steps, in one or more additive manufacturing machines **100** to achieve repair segments **74** that may include a plurality of layers formed from multiple different types of additive powders having different compositions, physical properties, etc.

[0090] Notably, complementary fixture **220** is generally configured for filling volume of build chamber **134** or powder bed which is otherwise not occupied by blades **70**, component fixtures **202**, or other mounting structures for supporting these components. In this manner, the process for supplying or loading additive powder **142** into powder bed is simplified. For example, an operator need only fill the gaps between the components to be repaired, e.g., blades **70**, and complementary fixture **220**. In this manner, the time required to prepare the additive manufacturing machine **100** for the print process is reduced, as is the amount of additive powder **142** that must be used and the required time for post processing of blades **70** and additive powder **142**.

[0091] Now that the construction and configuration of additive repair system **50** has been described according to exemplary embodiments of the present subject matter, an exemplary method **300** for mounting a plurality of components for a repair or rebuild process using an additive repair system will be described according to an exemplary embodiment of the present subject matter. Method **300** can be used to repair blades **70** using additive repair system **50**, AM machine **100**, and tooling assembly **200**, or to repair any other suitable component using any other suitable additive manufacturing machine or system. In this regard, for example, controller **60** may be configured for implementing some or all steps of method **300**. Further, it should be appreciated that the exemplary method **300** is discussed herein only to describe exemplary aspects of the present subject matter, and is not intended to be limiting.

[0092] Referring now to FIG. 9, method **300** includes, at step **310**, mounting a component on a mounting plate such that a repair surface of the component is positioned within a build plane. In this regard, a plurality of blades **70** which need to be repaired may be positioned in corresponding component fixtures **202**, e.g., by sliding dovetails **204** of each blade **70** in a complementary slot **206** of each component fixture **202**. Component fixtures **202** may then be mounted to build platform **118** or mounting plate **210** in the desired position and orientation.

[0093] Step **320** includes positioning a complementary fixture over the mounting plate. As described above, complementary fixture **220** defines one or more voids **222** for receiving the component (or a plurality of components) such that a clearance gap **230** is defined between the component and complementary fixture **220**. In addition, clearance gap **230** may be designed such that the process of loading additive powder **142** is simplified and a top **238** of complementary fixture may be positioned below repair surface **72** of blades **70** such that the recoating process is simplified and the additive manufacturing process proceeds without contacting complementary fixture **220**.

[0094] Step 330 includes positioning the mounting plate, the component, and the complementary fixture on a build platform of an additive manufacturing machine. According to alternative embodiments, mounting plate 210 may be removed altogether, component fixtures 202 and blades 70 may be mounted directly to build platform 118, and complementary fixture 220 may be configured for mounting directly to build platform 118 over blades 70. In this manner, the plurality of blades 70 which need to be repaired are positioned within build chamber 134 or the powder bed such that the blades 70 and complementary fixture 220 substantially fill the powder bed (e.g., greater than 95% of the total volume) to simplify powder loading and the printing process.

[0095] According to an exemplary embodiment, method 300 may further include additively printing repair segments 74 onto repair surfaces 72 of each blade 70 using AM machine 100. In this regard, step 340 includes depositing a layer of additive powder over the repair surface of the component using a powder dispensing assembly and step 350 includes selectively irradiating the layer of additive powder to fuse the layer of additive powder onto the repair surface of the component. In this manner, an energy source may fuse additive powder onto each blade tip layer by layer until the component is repaired to an original CAD model or to another suitable geometry.

[0096] FIG. 9 depicts an exemplary control method having steps performed in a particular order for purposes of illustration and discussion. Those of ordinary skill in the art, using the disclosures provided herein, will understand that the steps of any of the methods discussed herein can be adapted, rearranged, expanded, omitted, or modified in various ways without deviating from the scope of the present disclosure. Moreover, although aspects of the methods are explained using additive repair system 50, AM machine 100, and tooling assembly 200 as an example, it should be appreciated that these methods may be applied to repairing or rebuilding any other number, type, and configuration of components using any suitable tooling fixture or additive manufacturing machine or system.

[0097] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they include structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

What is claimed is:

1. A tooling assembly for supporting a component during a powder bed additive manufacturing process, the tooling assembly comprising:

a mounting plate configured for receiving the component such that a repair surface of the component is positioned within a build plane; and

a complementary fixture defining a void corresponding to the component such that positioning the complementary fixture over the mounting plate positions the component within the void.

2. The tooling assembly of claim 1, wherein a clearance gap is defined between the component and the complementary fixture when the complementary fixture is positioned over the mounting plate.

3. The tooling assembly of claim 2, wherein the clearance gap has a width that is constant along a height of the complementary fixture.

4. The tooling assembly of claim 3, wherein the clearance gap is approximately 1 millimeter all the way around the component.

5. The tooling assembly of claim 1, wherein the clearance gap has a width that increases gradually from a bottom of the complementary fixture toward a top of the complementary fixture.

6. The tooling assembly of claim 1, wherein the void corresponds substantially to the shape of a blade of a gas turbine engine.

7. The tooling assembly of claim 1, wherein a top surface of the complementary fixture is positioned at or below the build plane when the complementary fixture is positioned over the mounting plate.

8. The tooling assembly of claim 1, wherein the complementary fixture is formed from a metal, ceramic, or plastic material.

9. The tooling assembly of claim 1, wherein a layer of additive material is deposited over the complementary fixture and the repair surface of the component.

10. The tooling assembly of claim 9, wherein the layer of additive material is a different material than the component.

11. The tooling assembly of claim 1, wherein the complementary fixture is formed by:

obtaining a component CAD model of the component mounted to the mounting plate; and

determining a fixture model by removing the component CAD model from a CAD model of a solid three-dimensional volume corresponding to a powder bed.

12. The tooling assembly of claim 11, wherein the complementary fixture is formed by additively manufacturing the fixture model.

13. The tooling assembly of claim 1, wherein the mounting plate is configured for receiving a plurality of components and the complementary fixture defines a plurality of voids, each of the plurality of voids corresponding to one of the plurality of components such that positioning the complementary fixture over the mounting plate positions the plurality of components within the plurality of voids.

14. A method of repairing a component using an additive manufacturing machine, the method comprising:

mounting the component on a mounting plate such that a repair surface of the component is positioned within a build plane; and

positioning a complementary fixture over the mounting plate, the complementary fixture defining a void for receiving the component, and wherein a clearance gap is defined between the component and the complementary fixture.

15. The method of claim 14, further comprising:

positioning the mounting plate, the component, and the complementary fixture on a build platform of the additive manufacturing machine;

depositing a layer of additive powder over the repair surface of the component using a powder dispensing assembly; and

selectively irradiating the layer of additive powder to fuse the layer of additive powder onto the repair surface of the component.

16. The method of claim **14**, wherein the clearance gap has a width that is constant along a height of the complementary fixture.

17. The method of claim **14**, wherein the clearance gap has a width that increases gradually from a bottom of the complementary fixture toward a top of the complementary fixture.

18. The method of claim **14**, wherein a top surface of the complementary fixture is positioned at or below the build plane when positioned over the mounting plate.

19. The method of claim **14**, further comprising forming the complementary fixture by:

obtaining a component CAD model of the component mounted to the mounting plate; and

determining a fixture model by removing the component CAD model from a CAD model of a solid three-dimensional volume corresponding to a powder bed.

20. The method of claim **14**, comprising:

mounting a plurality of components on the mounting plate such that a repair surface of each of the plurality of components is positioned within the build plane; and positioning the complementary fixture over the mounting plate, the complementary fixture defining a plurality of voids, each of the plurality of voids corresponding to one of the plurality of components such that positioning the complementary fixture over the mounting plate positions the plurality of components within the plurality of voids.

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