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(54) **ROBOTIC DEEP ROLLING TOOL DESIGN FOR MECHANICAL SURFACE TREATMENT OF COMPLEX BLADE ROOT GEOMETRY**

(57) A system for deep rolling a workpiece including a roller tool comprising an adaptor plate proximate an adapter end; an arm attached to the adaptor plate, the arm comprising an adapter end proximate the adaptor plate, the arm comprising a roller end opposite the adapter end, the arm comprising a midspan portion between the adapter end and the roller end, an offset formed in the arm configured to prevent contact with the workpiece; a roller disk joined to the roller end, the roller disk configured to contact the workpiece; and a fixture supporting the workpiece.

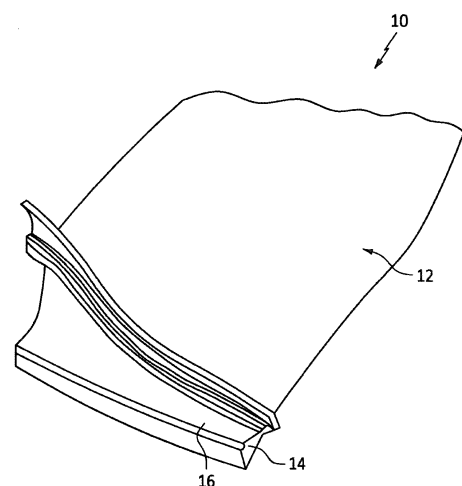


FIG. 1

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Description

[0001] The present disclosure is directed to a system for deep rolling surfaces of a fan blade. Particularly, a deep rolling (DR) process can be used on aluminum fan blade roots to improve damage tolerance from corrosion. This can increase fatigue life or maintain fatigue life in the presence of damage.

[0002] Mechanical surface treatments are applied to alter surface strength & enhance fatigue life. Deep Rolling (DR) is a type of surface treatment. The Deep Rolling process uses a roller to roll the surface under controlled load & speed. The rolling pressure induces a deep layer of compressive residual stress. Mechanical surface treatments, such as Deep Rolling, shot peening and laser shock peening, can significantly improve the fatigue behavior of highly stressed metallic components. Deep rolling is particularly attractive since it is possible to generate, near the surface, deep compressive residual stresses and work hardened layers while retaining a relatively smooth surface finish.

[0003] Hydraulic burnishing tools for complex geometries utilize a ball bearing at the end of an axisymmetric, hydraulically actuated shaft. However, this tool is expensive and it involves complex processing steps. Further, despite its relatively high precision, the small surface area of a ball bearing unnecessarily slows production time and throughput. These known tools also cannot be readily used with widely available machine tools due to the need to maintain and constantly adjust hydraulic pressure on the bearing surface. In addition, there is a need for a post processing to clean the treated surface from the oil residue left on the surface.

[0004] An alternative process includes a dry deep rolling process, which can induce high compressive stresses up to 1.5 mm depth from the surface of a material through localized plastic deformation to prevent corrosion pits, foreign object damage, and crack initiation.

[0005] Controlling the contact stress between the roller and material being processed is important to achieving desired improvements in material properties. With insufficient contact stress, little or no improvement will be achieved. In addition, there is also a need to customize the applied load and consequently the contact stress along the deep rolling path. Too high of a contact stress can damage the material on/near the surface resulting in a decrement in properties. Avoiding collision between the deep rolling tool and the fan blade is desired to prevent the creation of defects in the blade or scrapping the blade.

[0006] In accordance with the present disclosure, there is provided a system for deep rolling a workpiece comprising a roller tool comprising an adaptor plate proximate an adapter end; an arm attached to the adaptor plate, the arm comprising an adapter end proximate the adaptor plate, the arm comprising a roller end opposite the adapter end, the arm comprising a midspan portion between the adapter end and the roller end, an offset formed in the arm configured to prevent contact with the workpiece; a

roller disk joined to the roller end, the roller disk configured to contact the workpiece; and a fixture supporting the workpiece.

[0007] Particular embodiments further may include at least one, or a plurality of, the following optional features, alone or in combination with each other:

A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the arm comprises at least one stiffener formed proximate the midspan portion.

[0008] A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the system for deep rolling a fan blade further comprising a roller disk support attached to the roller end, the roller disk support comprising an interlock feature configured to mate with the arm proximate the roller end.

[0009] A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the roller disk support comprises an integral axel configured to support the roller disk.

[0010] A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the roller disk support comprises a tapered portion configured to reduce contact with the workpiece.

[0011] A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the roller disk support comprises at least one bore configured to accept a fastener configured to attach the roller disk to the roller end of the arm.

[0012] A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the arm comprises a curved feature formed along the arm proximate the roller end.

[0013] In accordance with the present disclosure, there is provided a system for deep rolling a fan blade comprising a roller tool comprising an adaptor plate proximate an adapter end; an arm attached to the adaptor plate, the arm comprising an adapter end proximate the adaptor plate, the arm comprising a roller end opposite the adapter end, the arm comprising a midspan portion between the adapter end and the roller end, an offset formed in the arm configured to prevent contact with a root of the fan blade; a roller disk joined to the roller end, the roller disk configured to contact the root; and a fixture supporting the fan blade the fixture comprising a body including an upper region opposite a lower region, the body includes a front and a rear opposite the front, the body includes a right side and a left side opposite the right side; the body supports a pivot clamp, the pivot clamp attaches to the body with a pivot attached to the body; a support attached to the body, the support includes at least one brace coupled to the rear of the body, the support is configured to engage an airfoil portion of the fan blade; a receiver formed in the body configured to support the root of the fan blade, wherein the receiver includes at least one landing configured to support a corresponding portion of the root; and a shoulder attached to the body config-

ured to support a platform portion of the fan blade; wherein the shoulder is located in an upper region of the body between the receiver and the support.

[0014] Particular embodiments further may include at least one, or a plurality of, the following optional features, alone or in combination with each other:

A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the arm comprises at least one stiffener formed proximate the midspan portion, the stiffener extending radially relative to a longitudinal axis of the arm.

[0015] A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the system for deep rolling a fan blade further comprising a roller disk support attached to the roller end, the roller disk support comprising an interlock feature configured to mate with the arm proximate the roller end, the interlock feature comprising a concave surface configured to mate with a matching convex surface on the arm.

[0016] A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the roller disk support comprises an integral axel configured to support the roller disk.

[0017] A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the roller disk support comprises a tapered portion opposite the axel, the tapered portion configured to reduce contact with the fan blade.

[0018] A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the roller disk support comprises at least one bore configured to accept a fastener configured to attach the roller disk to the roller end of the arm.

[0019] A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include a process for forming a roller tool for deep rolling a fan blade comprising the roller tool comprising an adaptor plate proximate an adapter end; attaching an arm to the adaptor plate, the arm comprising an adapter end proximate the adaptor plate, the arm comprising a roller end opposite the adapter end, the arm comprising a midspan portion between the adapter end and the roller end, an offset formed in the arm configured to prevent contact with the fan blade; joining a roller disk to the roller end, the roller disk configured to contact the fan blade; and supporting the fan blade with a fixture.

[0020] A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the process further comprising forming at least one stiffener in the arm proximate the midspan portion; and extending the stiffener radially relative to a longitudinal axis of the arm.

[0021] A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the process further comprising attaching a roller disk support to the roller end; forming an interlock feature in the roller disk support; and configuring the interlock

feature to mate with the arm proximate the roller end; wherein the interlock feature comprises a concave surface configured to mate with a matching convex surface on the arm.

[0022] A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the process further comprising forming an integral axel in the roller disk support; and configuring the integral axel to support the roller disk.

[0023] A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the process further comprising forming a tapered portion opposite the axel; and configuring the tapered portion to reduce contact with the fan blade.

[0024] A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the process further comprising forming at least one bore in the roller disk support; configuring the at least one bore to accept a fastener configured to attach the roller disk to the roller end of the arm.

[0025] A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the process further comprising forming an offset feature in the arm; configuring the offset feature to enable the roller disc to contact with the fan blade at a working surface and avoid contact of the arm with the fan blade.

[0026] Other details of the system for deep rolling are set forth in the following detailed description and the accompanying drawings wherein like reference numerals depict like elements.

FIG. 1 is a perspective view of a dovetail root portion of a gas turbine engine fan blade.

FIG. 2 shows a roller processing a workpiece such as a blade root shown in FIG. 1.

FIG. 3 is a perspective view of an embodiment of a deep rolling tool.

FIG. 4 is an exploded view of the deep rolling tool embodiment in FIG. 3.

FIG. 5 shows an embodiment of a deep rolling tool attached to a robot arm for accessing difficult to process areas of a workpiece with the deep rolling tool.

Fig. 6 is an isometric view of an exemplary fixture with a fan blade mounted.

Fig. 7 is a detailed view of the exemplary fixture with a fan blade mounted.

Fig. 8 is a side view of the exemplary fixture with fan blade mounted.

Fig. 9 is a side view of the exemplary fixture with fan blade mounted.

Fig. 10 is an isometric view of the exemplary fixture with fan blade mounted.

Fig. 11 is an isometric view of a detail in the exemplary fixture with fan blade mounted.

Fig. 12 is a side view of the exemplary fixture with fan blade mounted.

Fig. 13 is a side view of the exemplary fixture with fan

blade mounted.

Fig. 14 is an isometric view of an exemplary roller tool and workpiece.

Fig. 15 is a multi-view isometric view of an exemplary roller tool and workpiece.

Fig. 16 is an isometric view of an exemplary roller tool and workpiece.

Fig. 17 is a side view of an exemplary roller tool and workpiece.

Fig. 18 is a side view of an exemplary roller tool and workpiece.

Fig. 19 is a side view of an exemplary roller tool.

Fig. 20 is an isometric view of an exemplary roller tool.

Fig. 21 is a side view of an exemplary roller tool arm.

Fig. 22 is a side view of an exemplary roller tool arm.

Fig. 23 is an x-ray side view of an exemplary roller tool arm with roller.

Fig. 24 is a perspective view of an exemplary arm and roller.

Fig. 25 is a side view of an exemplary roller tool.

Fig. 26 is a side cross-section view of an exemplary roller tool and roller.

Fig. 27 is a perspective view of an exemplary roller tool and roller.

Fig. 28 is a perspective view of an exemplary roller tool and roller.

Fig. 29 is a perspective view of an exemplary roller tool.

Fig. 30 is a perspective view of an exemplary roller tool and roller.

Fig. 31 is an end view of an exemplary roller tool.

[0027] Generally, a roller disk with a crowned or otherwise nonplanar working surface about its perimeter can be attached to an end of a shaft. The tool can be attached to a device to process one or more parts. The tool uses multiple tools passes to induce residual compressive stresses while maintaining the appropriate level or range of contact stresses at the roller's point of contact via selective spring loading of the tool. A fixture is utilized to secure the part for use of the tool to perform the deep rolling.

[0028] FIG. 1 shows workpiece 10, which can be supported in a suitable fixture (not shown). Workpiece 10 has airfoil 12 and dovetail root 14. At least one nonplanar surface is to be processed (e.g., junction 16 between airfoil 12 and root 14) to have residual compressive stresses near the surface in and around junction 16.

[0029] In this example, workpiece 10 is an aluminum alloy hollow fan blade for a turbofan engine, but the process can be adapted to nearly any workpiece having a nonplanar surface into which residual compression stresses are desired to be incorporated.

[0030] Thus, in the example of a dovetail-rooted blade, it is desired to increase residual compressive stresses around both sides of junction 16 between dovetail root 14 and airfoil 12. As most of the bending stresses are con-

centrated around junction 16, this location is most prone to fatigue damage. The combined effects of fatigue and corrosion pitting can be reduced via deep rolling because the residual compressive stress induced by application of the rolling tool (shown in subsequent figures) reduces the pathways for damage to propagate through the part, extending the time before failure or replacement.

[0031] FIG. 2 shows roller disk 20 processing junction 16 of workpiece/blade 10 between airfoil 12 and root 14. Disk 20 can be joined to a portion of hub 22 with roller disk 20 rotatable about an axis 24 angled relative to a downward force direction F. Here, axis 24 is normal to downward force direction F and thus, resulting downward contact force is applied to junction 16 generally in direction F as well.

[0032] Disk 20 has working surface 26 about its perimeter 28 and can include a profile along its width 30 (best seen in FIGS. 3 and 4), such that an effective radius of the roller disk varies along a width thereof. It can be seen in FIG. 2 that the disk should be of a radius that provides clearance over protruding regions of the workpiece (e.g., dovetail root 14). In a conventional arrangement for processing a modern aluminum fan blade dovetail, this requires a minimum disk radius of about 2 inches (51 cm), but the size will vary depending on a particular application.

[0033] Hub 22 connects disk 20 to a shaft through which the downward force can be applied in direction F. One example embodiment of a deep rolling tool incorporating this construction is shown in FIG. 3. Tool assembly 31 includes spring-loaded shaft assembly 32 disposed along axis 34, which is parallel to downward force direction F. Hub 22 can have a first/upper portion 36A along axis 34 and a second/lower portion 36B at a nonzero angle relative to axis 34. This angle is therefore consistent with the nonzero angle between axis 24 and direction F.

[0034] Operation of tool assembly 31 can be as follows. The rolling operation can include applying a force in direction F along axis 34 such that the applied force is transferred through spring-loaded shaft assembly 32, hub 22, and roller disk 20 to a first nonplanar surface of the workpiece (e.g., junction 16). The resulting force applied to the first nonplanar surface varies along the width of working surface 26 of the disk due to the variable profile across width 30 (seen in FIG. 2).

[0035] At least one rolling operation can be performed on a nonplanar surface using a tool like that shown in FIG. 3. FIG. 3 depicts roller disk 20 joined to second/lower portion 36B of hub 22, and which is rotatable about axis 24 through second/lower portion 36B of hub 22. Roller disk 20 can be supported on one or more bearings (best seen in the exploded view of FIG. 4). As noted with respect to FIG. 2, disk 20 can have working surface 26 about perimeter 28 and can include a variable or crowned profile. As a result, an effective radius (and thus applied bearing stresses) of roller disk 20 varies along working surface 26. Though shown as a crowned roller with a

single center peak, working surface 26 can additionally have one or more peaks, troughs, etc. The resulting profile can thus either be curved, slanted, or flat.

[0036] Spring-loaded shaft assembly 32 can take several different forms. In one non-limiting example, resilient element 46 is disposed at distal end 48 of shaft assembly 32, while a rigid shaft 50 (best seen in FIG. 4) can be supported on a device to restrain its movement only along first axis 34. This can include one or more linear bearings 49. In other embodiments, shaft assembly 32 can include a flexible beam without a separate resilient element.

[0037] Regarding resilient element 46, certain non-limiting embodiments include a plurality of stacked Belleville washers 52 which can be selected in number and properties in order to provide a desired level of resilience. Alternatively, resilient element 46 can include a diaphragm spring or the like.

[0038] Certain embodiments of tool assembly 31 can also optionally include other elements. For one, tool assembly 31 can include tool holder 56 mounted to proximal end 58 of rigid shaft 50 and/or shaft assembly 32. Tool holder 56 can be a standard or custom adapter or other device to facilitate attachment of tool assembly 31 to commercially available multi-axis computerized numerical control (CNC) machines (not shown). Tool holder 56 can additionally or alternatively facilitate attachment to other devices capable of steering tool assembly 31 while simultaneously applying sufficient (but not excessive) force in downward direction F to induce the desired compressive stresses.

[0039] In certain embodiments, tool assembly 31 can include load cell 60 to measure the force at the contact surface (see FIG. 4). Load cell 60 can optionally be disposed along axis 34 adjacent to resilient element 46 and can include a wired and/or wireless connection 62 for controller 64. This will be explained in more detail below.

[0040] FIG. 4 shows an exploded view of tool assembly 31 from FIG. 3. In addition to the elements described generally above, tool assembly 31 can include the following details. As noted, shaft assembly 32 is restricted to movement only along first axis 34. Thus, in this example embodiment, shaft assembly 32 can include linear bearing 48 arranged along axis 34 for supporting solid shaft 50. This simplifies determination of the downward force that needs to be applied in direction F, as any deflection away from that axis causes a reduction in the actual downward force vectors, while also applying unwanted transverse forces on the tool working surface.

[0041] In the example shown, hub 22 includes first and second portions 36A, 36B which form a right, or other, angle therebetween. Roller disk 20 is supported on a bearing or other device so that it is rotatable about axis 24. Here, with the right angle, axis 24 is perpendicular to first axis 34. In this example, working surface 26 of roller disk 20 is symmetrically crowned from a center to opposing first and second edges. Alternatively, working surface varies according to a desired load profile along the tool path and can include peaks, troughs, curves, etc.

[0042] Shaft assembly 32 can be calibrated before or between uses to provide a desired force concentration at working surface 26 of roller disk 20. In the example shown, at least one of solid shaft 50 and resilient element 46 can be calibrated so that the force applied to the tool in direction F (shown in FIGS. 2 and 3) and transmitted through roller disk 20 is sufficient to impart a residual compression stress in the workpiece at the first nonplanar surface (e.g., junction 16 in FIGS. 1 and 2).

[0043] The deep rolling tool described heretofore can be used in a number of different applications, depending on the required accuracy and precision of the applied forces needed. Success in some cases can be achieved by merely controlling the tool load within previously determined upper and lower bounds, such as through spring loading the tool and applying a target amount of compression to the spring. The compliance obtained by using a spring-loaded tool enables an acceptable level of load control during processing but there is no record of what the actual contact stress was over the surface. However, this is the cheapest and often simplest option, where any suitable mechanical device with an ability to provide a controlled downward force can be used.

[0044] Some parts, however, require that the actual residual stresses at the working surface be verified. There are currently no non-destructive evaluation techniques that can be used to verify the correct level of residual stress was achieved during processing. Thus, a load cell or another feedback mechanism can be incorporated into the tool that allows monitoring and/or real-time adjustment of the force applied through the roller to the workpiece. The tool can process a part using multiple tool passes while maintaining the appropriate level of contact stress at the roller's point of contact. In some cases, the feedback is logged for quality control, so that it can be determined whether any irregularities occurred in the process. The load profile across the surface of the workpiece 10 can be varied. For example, the load applied to the workpiece 10 surface can be a lower value initially proximate the edges of the workpiece 10 and then be a higher value across the workpiece 10 and then include a lower value as the roller nears the opposite edge of the workpiece 10 just prior to finishing the pass. The load can be applied in a consistent fashion across the surface of the workpiece 10 that is being DR treated. The load profile can be customized across the surface of the workpiece 10 by use of the position and force sensors, such as, load cell 60 and controller 64.

[0045] As was shown and described above, load cell 60 can optionally be incorporated into tool assembly 32. Load cell 60, in certain embodiments, is contiguous to resilient element 46 (e.g., plurality of Belleville washers 52), and enables real time monitoring of the applied load during processing. A deep rolling tool with an integral load cell thus enables verification of a key process parameter, roller load, which is critical for quality control in many production environments.

[0046] Process consistency could be further enhanced

by using the load cell for closed loop load control which improve the precision with which the load could be maintained. Such a system would be much more tolerant of dimensional variability in the components being processed. It will also ensure that there are no micro-cracks on surface due to inadvertent localized application of intensive pressure.

[0047] Load cell 60 can be in wired or wireless communication with a controller 64 and/or monitor adapted to receive wired or wireless signals corresponding to an instantaneous load on resilient element 46. Controller/monitor 64 can include closed-loop feedback logic, by which it can be adapted to vary a force applied in direction F (see also FIGS. 2 and 3) on tool assembly 31, along axis 34. Operating load cell 60 can generate signals corresponding to an instantaneous load on resilient element 46. The magnitude of the force can be based at least in part on one or more of the signals received from and generated by load cell 60. The applied force is varied based on a plurality of signals from load cell 60 to impart a substantially equal residual compression stress in the workpiece along a tool rolling path on the first nonplanar surface. In an exemplary embodiment, a high-speed camera 66 can be utilized as a vision sensor to check any anomalies and integrate decision making algorithms in the robot controller 64 for direct adjustment of DR parameters or DR path for correcting the system.

[0048] The nature of many tools for CNC machines requires that they be axisymmetric (generally to facilitate rotation of the tool working end). Thus, CNC programming and many common subroutines are generally tailored to this expectation. In contrast, the non-axisymmetric nature of tool assembly 31 can require that the CNC machine be provided with more complex programming even for some relatively simple tool paths. Depending on the desired tool paths and number of passes, programming and use of a CNC machine may be unnecessary or prohibitively complex, in which case, tool assembly 31 can be mounted to a different machine to apply the desired force over the contact path. While certain processes can generally be performed using a specialized tool in a conventional CNC milling machine, the deep rolling tool can be inconsistent with generic subroutines and tool paths used to manipulate conventional axisymmetric tools. Therefore, use of the deep rolling tool, which is not axisymmetric, has additional path programming constraints. While planar surfaces can be processed by the deep rolling tool using a 3-axis CNC machine, more complex geometry components will require at least a 5-axis machine and in some instances a 6-axis machine may be necessary. Maintaining the normality and orientation constraints for deep rolling of complex component geometries can be challenging as the tool path programming software won't automatically satisfy these required constraints. While creative programming can generally overcome these issues it may require an experienced and highly skilled programmer.

[0049] To overcome this, deep rolling tool assembly 31

can be attached to the end of a robotic arm 100 as shown in FIG. 5. Robotic assembly 100 can include, for example, a plurality of linear arms 102 connected in series between base end 104 and working end 106. Adjacent ones of arms 102 can be connected via a corresponding plurality of multi-axis joints 110 such that working end 106 is articulated by movement of one or more of arms 102 relative to one or more of multi-axis joints 110.

[0050] Operation of a robotic assembly such as assembly 100 in FIG. 5 can include using it to apply a downward force over a rolling path of non-axisymmetric deep rolling tool assembly 31. The downward force is applied to a proximal end of a spring-loaded tool shaft (best seen in FIG. 2) aligned with a first axis, such that the downward force is transferred through the shaft to a hub disposed at a distal end of the shaft assembly (also best seen in FIG. 2). In certain embodiments, robotic assembly 100 is sufficiently programmed and/or controlled to provide the appropriate instantaneous feedback of downward force, and the resilient element in tool 31 can be modified or omitted as needed.

[0051] As described above, the transferred downward force is transmitted from an upper portion of the hub aligned with the first axis to a lower portion of the hub parallel to a second axis. The second axis forms a non-zero angle relative to the first axis, about which a roller disk is supported by one or more bearings. A resulting compressive force is applied to the first nonplanar surface of the workpiece via a working surface of the roller disk.

[0052] A robot arm has more degrees of freedom than a 5-axis milling machine which facilitates processing of complex geometry parts. Current commercially available robot arms have been developed to the point where they can withstand the combination of high loads and precision required in deep rolling applications. The software for controlling robot arms is different to that for CNC milling machines and is more suited to maintaining the required orientation constraints of a multi-axis deep rolling tool. Also, it is easier to accommodate processing of large components using a robot arm, as the part does not have to fit inside the machine as it does with a milling machine.

[0053] Referring also to Fig. 6 through Fig. 13 a fixture 200 is shown with the workpiece, such as a hollow fan blade or simply fan blade 210 mounted. The fixture 200 includes a body 212. The body 212 includes an upper region 214 opposite a lower region 216. The body 212 includes a front 218 and a rear 220 opposite the front 218. The body 212 includes a right side 222 and a left side 224 opposite the right side 222.

[0054] The fixture 200 includes a pivot clamp 226 attached to the body 212. The pivot clamp 226 includes an arm 228 that attaches to the body 212 about a pivot 230. In an exemplary embodiment the arm 228 can be a C-shape design that can attach to the right side 222 and the left side 224 at pivot 230 on each side as shown.

[0055] The pivot clamp 226 includes an adjustable

clamp 232. The adjustable clamp 232 can be threaded and adjustably mounted through the arm 228. In an exemplary embodiment, other mechanical techniques can be employed to adjust the adjustable clamp 232, such as latches, levers, set screws and the like. The adjustable clamp 232 can translate linearly relative to the arm 228 by use of rotary motion via the threaded connection with the arm 228. The adjustable clamp 232 includes a hand knob 234 and a surface contactor 236 opposite the hand knob 234 along a shaft 238 of the adjustable clamp 232. The hand knob 234 can be manipulated to rotate the shaft 238. The adjustment of the adjustable clamp 232 can move the surface contactor 236 relative to the fan blade 210 to secure the fan blade 210 to the fixture 200.

[0056] The surface contactor 236 is configured to press against a portion of the fan blade 210 to secure the fan blade 210. In an exemplary embodiment the surface contactor 236 can press against the fan blade 210 proximate a platform 240 of the fan blade 210. The pivot clamp 226 can be moved relative to the pivot 230 such that the pivot clamp 226 can swing to allow for access to the upper region 214 of the fixture 200. The fan blade 210 can be installed or manipulated, such as being rotated for further processing. The pivot clamp 226 can be released allowing for the fan blade 210 to be moved and then secured to hold the fan blade 210 in place.

[0057] The fixture 200 includes a support 242 for maintaining the fan blade 210 secured. The support 242 can include at least one brace 244 coupled to the rear 220 of the body 212. The support 242 can extend upward relative to the upper region 214 to engage the airfoil 12 portion of the fan blade 210. In the exemplary embodiment shown, there are a pair of braces 242 that each include an adjustable strut 246. The brace 244 can be interchangeable with an alternative brace 244 with differing dimensions or shapes adapted for use with different fan blade 210 designs. In an exemplary embodiment the adjustable strut 246 can include a threaded shaft 248 that engages the brace 244 to translate by use of rotary motion and the threads formed in the strut 246 and brace 244. It is contemplated that other mechanisms can be employed to translate the shaft 248 relative to the strut 246, such as latches, levers, set screws, ratchet, detent ball and cavity, telescopic friction fittings and the like. The support 242 is shown with the struts 246 having a bend 250 that allows for a face 252 of the strut 246 to be approximately parallel to the airfoil 12, to enable the shaft 248 to be approximately perpendicular to the airfoil 12. The adjustable strut 246 allows for more precise adjustment and support of the fan blade 210. The support 242 helps to prevent unwanted deflection of the fan blade 210, especially along a length of the airfoil 12.

[0058] The fixture 200 includes a receiver 254 located in the upper region 214. The receiver 254 is configured to accept the root 14 of the fan blade 210. The receiver 254 includes a first landing 256, a second landing 258 and a

third landing 260. Each of the landings 256, 258 and 260 can be configured to match a portion of the root 14 to provide adequate surface to support the root 14 of the fan blade 210 while the deep rolling process is conducted on the exposed portion of the root 14 opposite the receiver 254. The landings 256, 258, 260 can be configured as planar surfaces. In exemplary an embodiment landing 256, 258, 260 can include a convex or concave surface structure designed to match the corresponding exterior surface of the root 14. The receiver 254 allows for the fan blade 210 to be removed and rotated so that the untreated surfaces of the root 14 can be processed by DR. The landings 256, 258, 260 can extend across the width of the upper region 214 from the right side 222 to the left side 224. The receiver 254 includes a lug 262 that extends outward to brace the root 14. The lug 262 can extend from the third landing 260. The lug 262 can be adjustable, able to be moved to accommodate various sizes/positions of root 14. The lug 262 is configured to secure the fan blade 210 in the receiver 254. The lug 262 can include mechanisms to adjust and move including a threaded shaft, latches, friction fitting, and the like.

[0059] The fixture 200 can include a shoulder 264 attached to the upper region 214. The shoulder 264 is configured to support the platform 240 portion of the fan blade 210. The shoulder 264 can be located in the upper region 214 between the receiver 254 and the support 242. The shoulder 264 can include a jaw structure 266 that is contoured to match the perimeter shape of the platform 240 of the fan blade 210. The shoulder 264 can provide support of the fan blade 210 against the forces applied by the pivot clamp 226, such that the fan blade 210 is secured between the pivot clamp 226 on one side and the shoulder 264 and the receiver 254 and the brace 244 on the opposite side of the fan blade 210. The shoulder 264 can be adjusted by use of fasteners 268 secured to the body 212. In an exemplary embodiment, the fasteners 268 can include mechanisms to adjust and move including a threaded shaft and nuts, latches, friction fitting, and the like.

[0060] The fixture 200 is configured to mount and secure the fan blade 210 in a position that allows access of the working surface 26 to the fan blade 210 in the absence of unwanted contact to the fan blade 210. The fixture 200 is configured to easily dismount the fan blade 210 and allow for the manipulation of the fan blade 210 to rotate the fan blade 210 and access surfaces for the DR process.

[0061] Referring also to Fig. 14 through Fig. 29, the exemplary roller tool 300 can be seen. The roller tool 300 can be an alternative to the tool assembly 31 described above. The roller tool 300 can include an adapter plate 310. The adapter plate 310 is configured to be attached to the working end 106 of the robotic assembly 100. The working end 106 of the robotic assembly 100 can include the load cell 60 otherwise known as a dynamic force controller in operative communication with the adaptor plate 310. The dynamic force controller is configured to

monitor the applied forces continuously during the deep rolling process. The adapter plate 310 has a flange section 312 with bolt holes 314 adapted to receive fasteners (not shown). The adapter plate 310 includes a receiver 316. The receiver 316 is adapted to receive an arm 318. The arm 318 includes an adapter end 320 and a roller end 322 opposite the adapter end 330. The adapter end 320 can be configured to couple with the receiver 316 to secure the arm 318 to the adapter plate 310. In an exemplary embodiment, the adapter end 320 is configured as a cylinder (as seen in Fig. 29) that fits into the cylinder shape of the receiver 316. Threaded fasteners 324 can be employed to secure the adapter end 320 to the receiver 316 of the adapter plate 310.

[0062] The arm 318 includes a midspan portion 326 located between the adapter end 320 and the roller end 322. The midspan portion 326 can include a stiffener 328 formed in the arm 318 that extends along the arm 318 between the adapter end 320 and the roller end 322. The stiffener 328 can extend radially from the arm 318 relative to an axis A (Fig. 29). The stiffener 328 can be formed as a longitudinal tee flange 330 and the like. The stiffener 328 can taper from the adapter end 320 to the roller end 322, decreasing in radial width along the length of the arm 318. There can be multiple stiffeners 328 that allows for the removal of excess material from the arm 318 while maintaining the structural integrity of the roller tool 300. The stiffeners 328 also allow for the arm 318 to include an offset feature 332 (Fig. 21), that enables the roller disc 20 to contact with the workpiece 10 at the working surface 26 and avoid unwanted contact of the arm 318 with the platform 240 or other portion of the workpiece 10.

[0063] The offset feature 332 allows for the avoidance of unwanted contact of the arm 318 with the workpiece 10 while maintaining the necessary roller disk 20 forces for conditioning the working surface 26. The arm 318 can include a curved feature 333 that enhances the avoidance of contact with the workpiece 10.

[0064] The arm 318 includes a roller disk support 334. The roller disk support 334 is attached to the arm 318 proximate the roller end 322. The roller disk support 334 includes a connector portion 336 that mates with the arm 318 roller end 322. The connector portion 336 can have a positioner mechanical interlock feature 337. The positioner mechanical interlock feature 337 can be dovetailed or shaped with a concave surface 338 that mates with a convex surface 340 of the arm 318. The concave surface 338 and convex surface 340 match and provide support in multiple directions to ensure the roller disk support 334 is anchored to the arm 318.

[0065] A pair of roller disk support 334 fasteners 342 are threaded to a pair of bores 344 (see Fig. 23). The fasteners 342 allow for multiple types of interchangeable roller disk supports 334 to be connected to the arm 318 responsive to the type of workpiece 10 being rolled.

[0066] The roller disk support 334 includes an axel 346 (see Fig. 31). The axel 346 can be formed integral with the roller disk support 334. The roller disk 20 can include

bearings 348 that support the roller disk 20 on the axel 346. An axel fastener 350 can be secured to the axel 346 to support the roller disk 20. The roller disk support 334 can include a tapered portion 352 (Fig. 28). The tapered portion 352 allows for a narrow profile and reduces the incidence of contact with workpiece 10. The roller disk support 334 includes a rib 354 configured to provide structural support and access for the fasteners 342 to insert into the bores 344. The rib 354 can allow for the tapered portion 352 to have a smaller profile, while maintaining the structure necessary to support the axel 346.

[0067] Standardized modeling can be conducted to analyze and optimize the forces necessary for deep rolling the workpiece and subsequently design the roller disk and roller tool.

[0068] A technical advantage of the disclosed system can include a contoured arm that can apply constant normal load to the surfaces being treated while avoiding unwanted contact with the workpiece.

[0069] Another technical advantage of the disclosed system can include the roller tool being designed and checked for any collision with the hollow fan blade surfaces.

[0070] Another technical advantage of the disclosed system can include the capacity for a high system repeatability of the surface finish produced that is within design specifications.

[0071] Another technical advantage of the disclosed system can include an interchangeable roller disk support, allowing for matching the workpiece and the roller disk.

[0072] There has been provided a system for deep rolling. While the system for deep rolling has been described in the context of specific embodiments thereof, other unforeseen alternatives, modifications, and variations may become apparent to those skilled in the art having read the foregoing description. Accordingly, it is intended to embrace those alternatives, modifications, and variations which fall within the broad scope of the appended claims.

Claims

1. A system for deep rolling a workpiece, particularly a fan blade, comprising:

a roller tool comprising an adaptor plate proximate an adapter end;

an arm attached to the adaptor plate, the arm comprising an adapter end proximate the adaptor plate, the arm comprising a roller end opposite the adapter end, the arm comprising a midspan portion between the adapter end and the roller end, an offset formed in the arm configured to prevent contact with the workpiece;

a roller disk joined to the roller end, the roller disk configured to contact the workpiece; and

a fixture supporting the workpiece.

2. The system for deep rolling a workpiece, particularly a fan blade, according to claim 1, wherein the arm comprises at least one stiffener formed proximate the midspan portion. 5
3. The system for deep rolling a workpiece, particularly a fan blade, according to claim 1 or 2, further comprising: 10
a roller disk support attached to the roller end, the roller disk support comprising an interlock feature configured to mate with the arm proximate the roller end.
4. The system for deep rolling a workpiece, particularly a fan blade, according to claim 3, wherein the roller disk support comprises an integral axel configured to support the roller disk. 15
5. The system for deep rolling a workpiece, particularly a fan blade; according to claim 3 or 4, wherein the roller disk support comprises a tapered portion configured to reduce contact with the workpiece. 20
6. The system for deep rolling a workpiece, particularly a fan blade, according to any of claims 1 to 5, wherein the roller disk support comprises at least one bore configured to accept a fastener configured to attach the roller disk to the roller end of the arm. 25
7. The system for deep rolling a workpiece, particularly a fan blade, according to any of claims 1 to 6, wherein the arm comprises a curved feature formed along the arm proximate the roller end. 30
8. The system for deep rolling a workpiece, particularly a fan blade, according to any of claims 1 to 7, wherein: 35

the roller tool comprises a dynamic force controller in operative communication with the adaptor plate; and
further comprising:

a fixture supporting the fan blade;
the fixture comprising:

a body including an upper region opposite a lower region, the body includes a front and a rear opposite the front, the body includes a right side and a left side opposite the right side;
the body supports a pivot clamp, the pivot clamp attaches to the body with a pivot attached to the body;
a support attached to the body, the support includes at least one brace

coupled to the rear of the body, the support is configured to engage an air-foil portion of the fan blade;
a receiver formed in the body configured to support the root of the fan blade, wherein the receiver includes at least one landing configured to support a corresponding portion of the root; and
a shoulder attached to the body configured to support a platform portion of the fan blade; wherein the shoulder is located in an upper region of the body between the receiver and the support.

9. A process for forming a roller tool for deep rolling a workpiece, particularly a fan blade, comprising:

the roller tool comprising an adaptor plate proximate an adapter end;
attaching an arm to the adaptor plate, the arm comprising an adapter end proximate the adaptor plate, the arm comprising a roller end opposite the adapter end, the arm comprising a midspan portion between the adapter end and the roller end, an offset formed in the arm configured to prevent contact with the fan blade;
joining a roller disk to the roller end, the roller disk configured to contact the fan blade; and
supporting the fan blade with a fixture.

10. The process of claim 9, further comprising:

forming at least one stiffener in the arm proximate the midspan portion; and
extending the stiffener radially relative to a longitudinal axis of the arm.

11. The process of claim 9 or 10, further comprising:

attaching a roller disk support to the roller end;
forming an interlock feature in the roller disk support; and
configuring the interlock feature to mate with the arm proximate the roller end; wherein the interlock feature comprises a concave surface configured to mate with a matching convex surface on the arm.

12. The process of claim 11, further comprising:

forming an integral axel in the roller disk support; and
configuring the integral axel to support the roller disk.

13. The process of claim 12, further comprising:

forming a tapered portion opposite the axel; and
configuring the tapered portion to reduce con-

tact with the fan blade.

- 14.** The process of any of claims 11 to 13, further comprising:

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forming at least one bore in the roller disk support;
configuring the at least one bore to accept a fastener configured to attach the roller disk to the roller end of the arm.

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- 15.** The process of any of claims 9 to 14, further comprising:

forming an offset feature in the arm;
configuring the offset feature to enable the roller disc to contact with the fan blade at a working surface and avoid contact of the arm with the fan blade.

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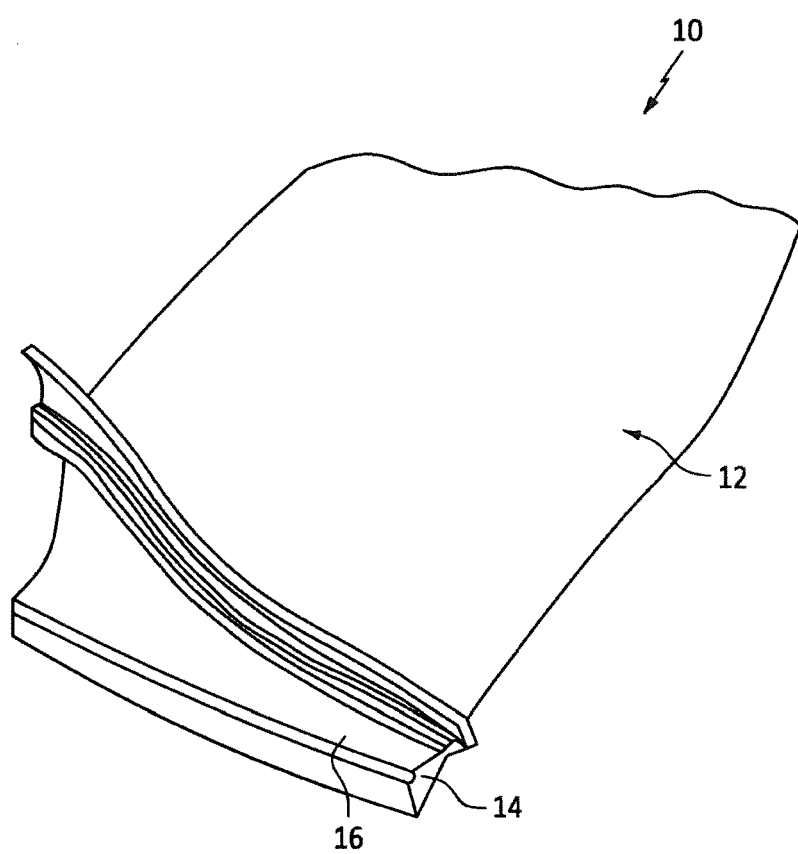


FIG. 1

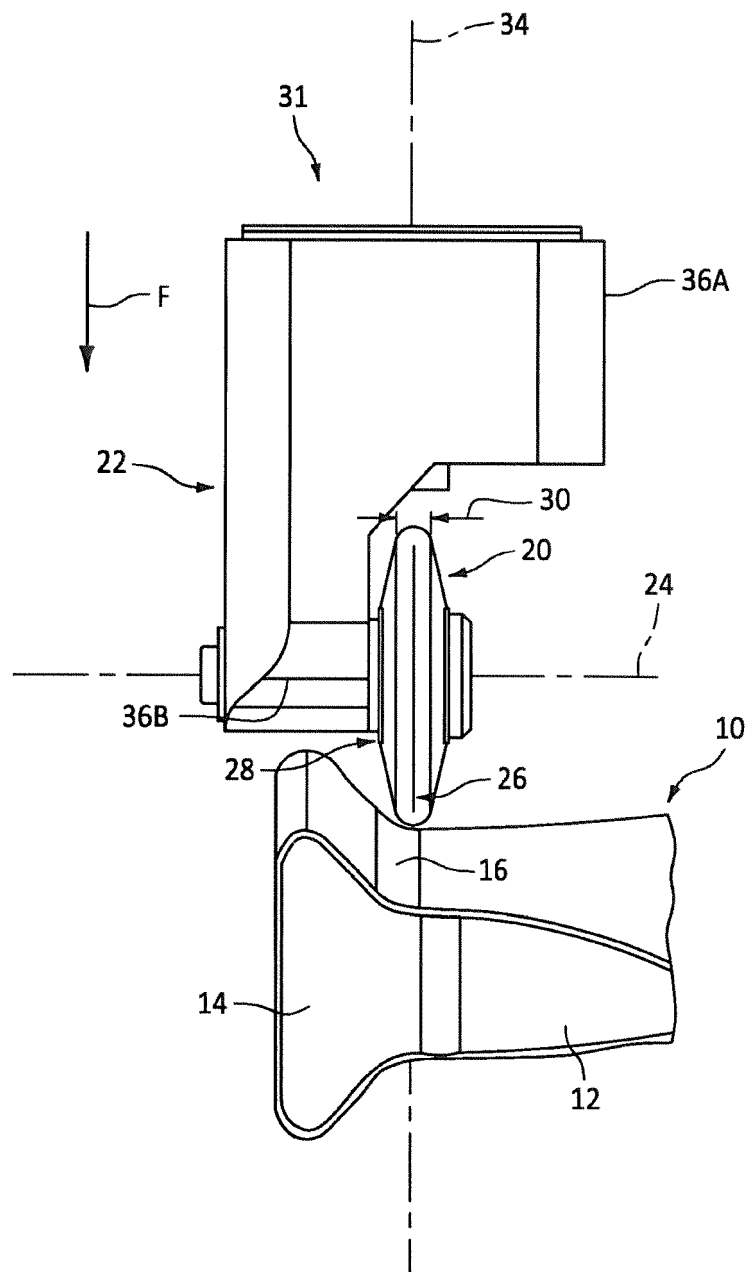


FIG. 2

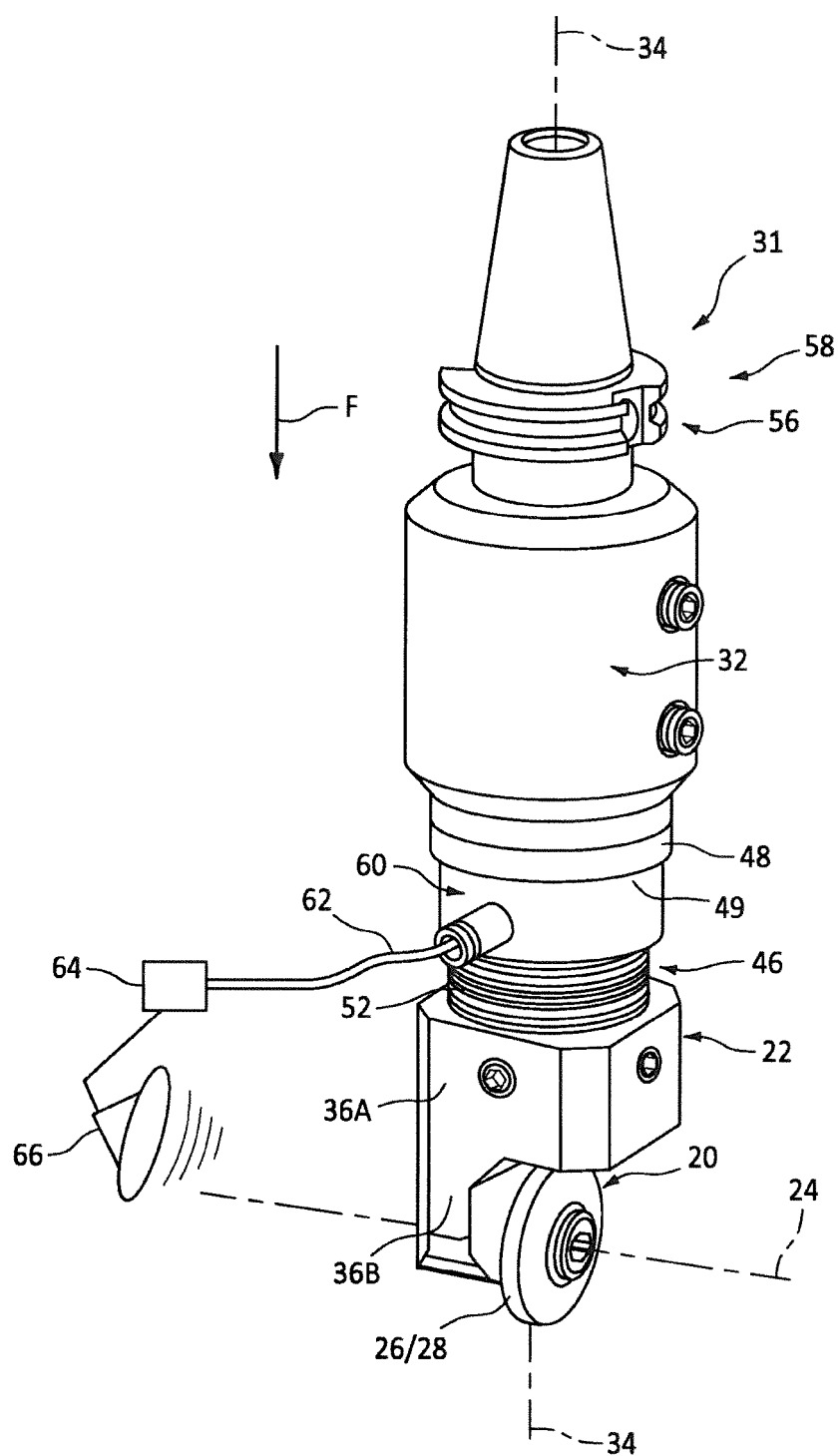


FIG. 3

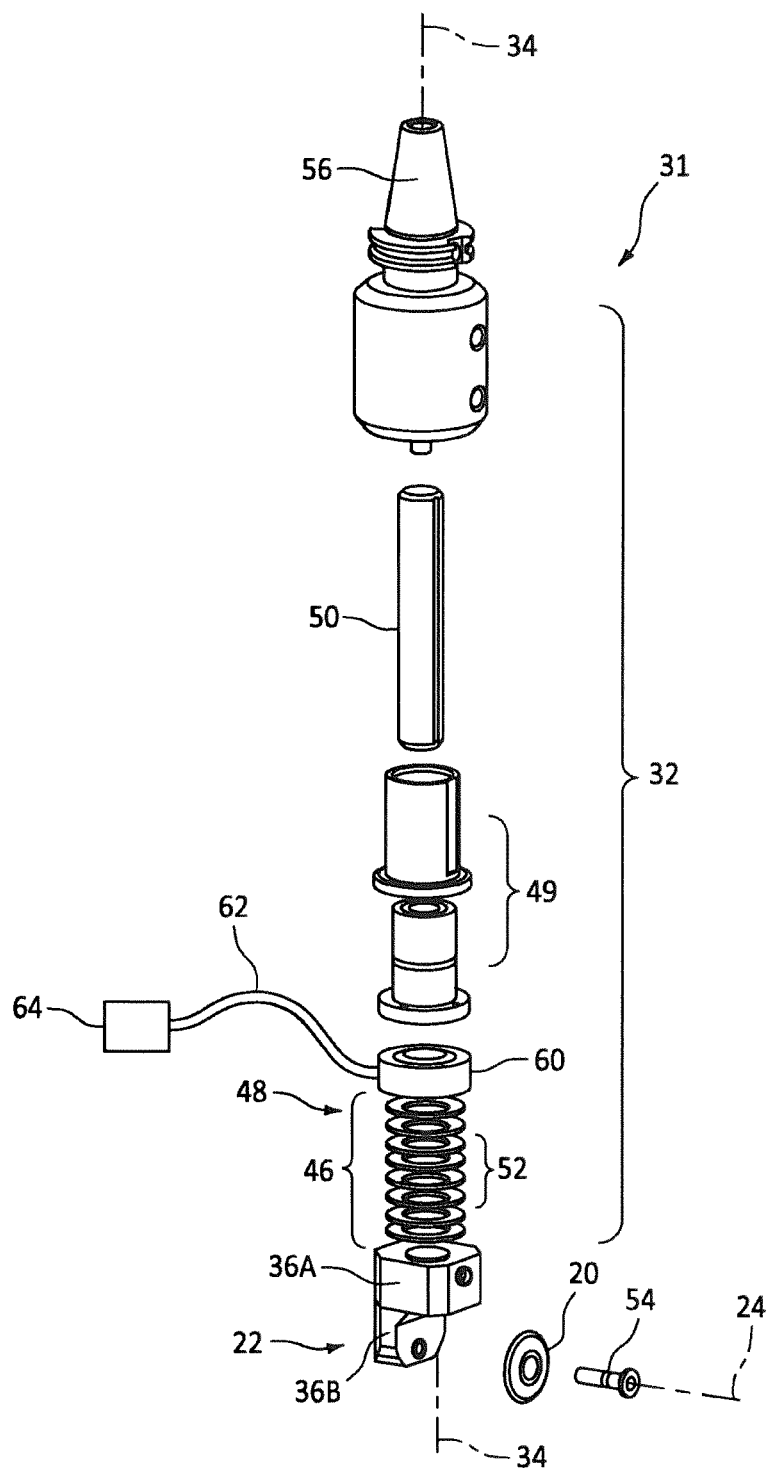


FIG. 4

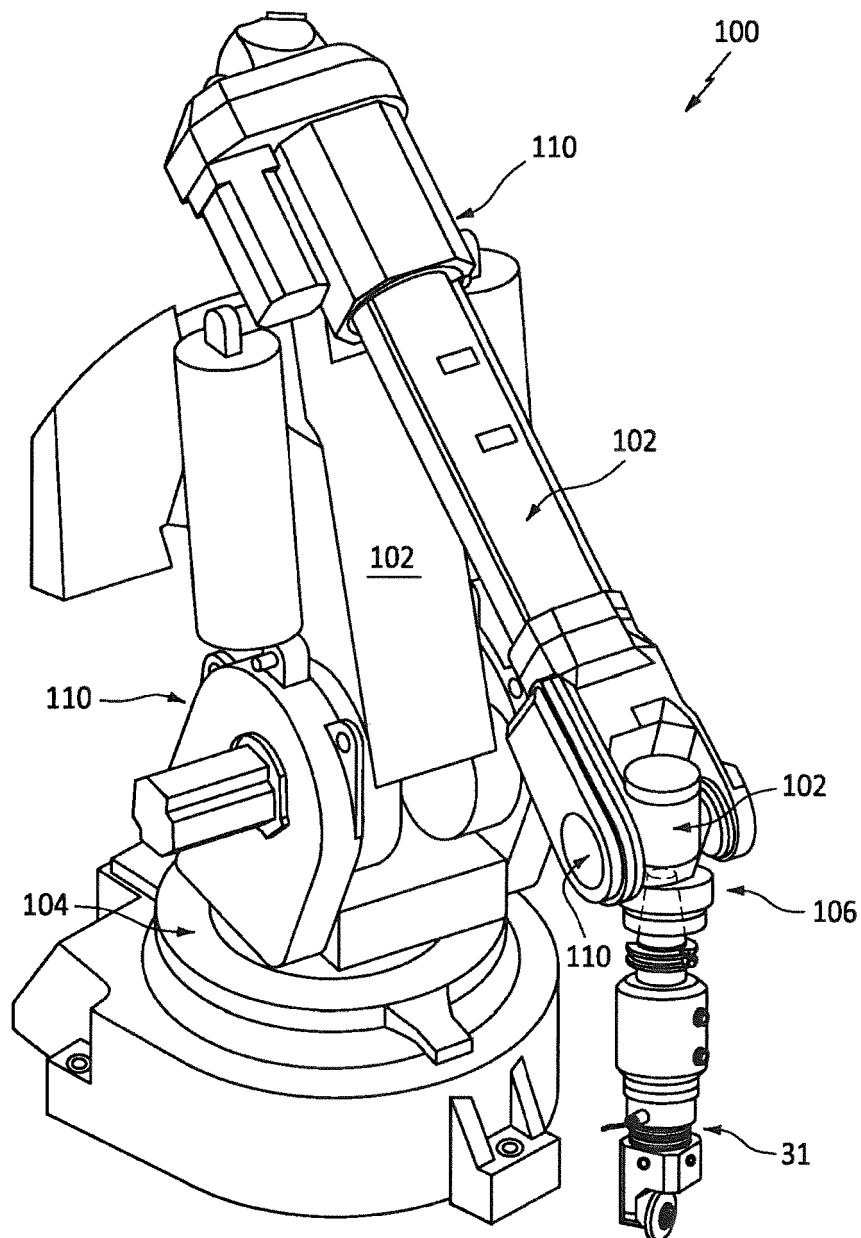
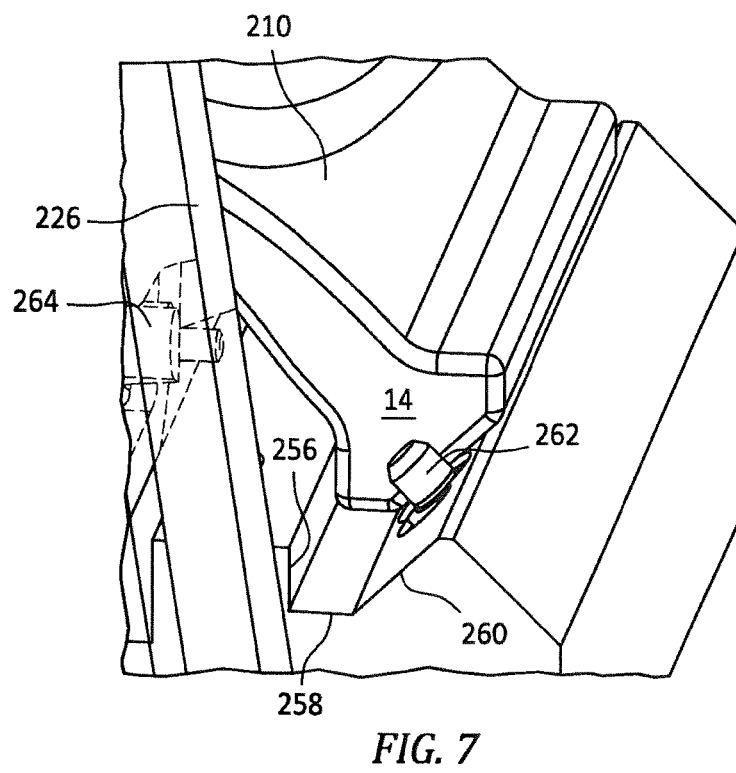
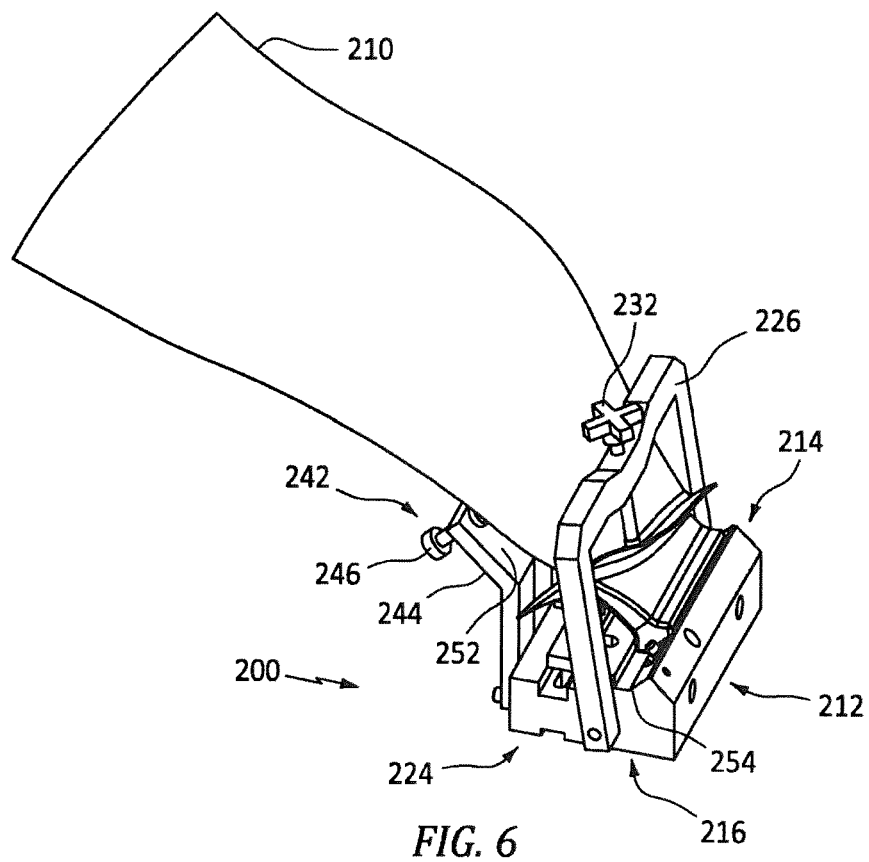
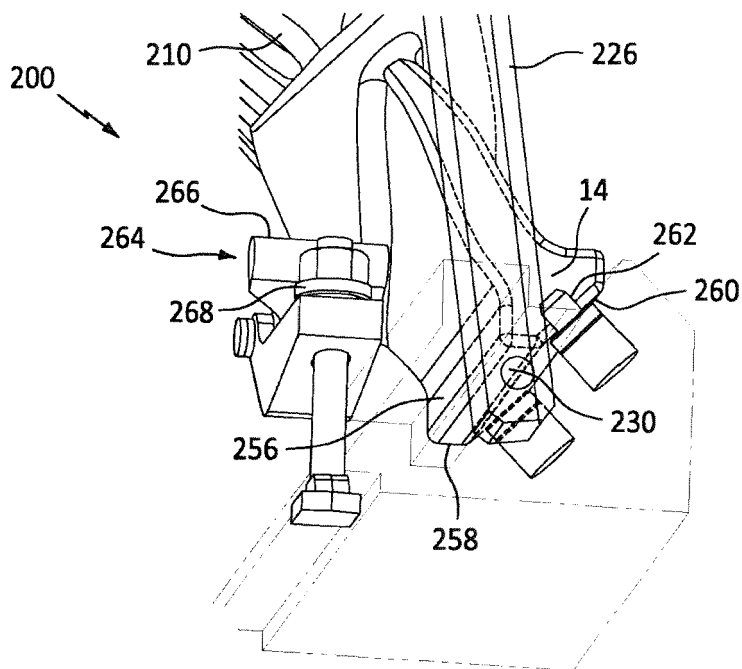
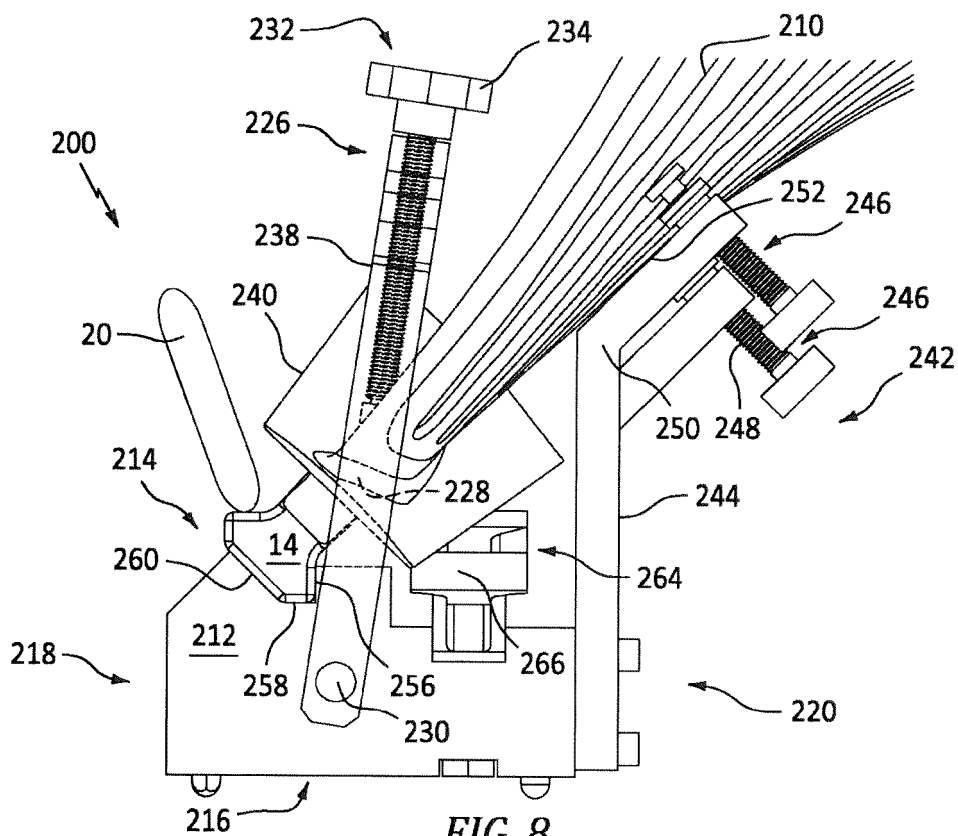


FIG. 5





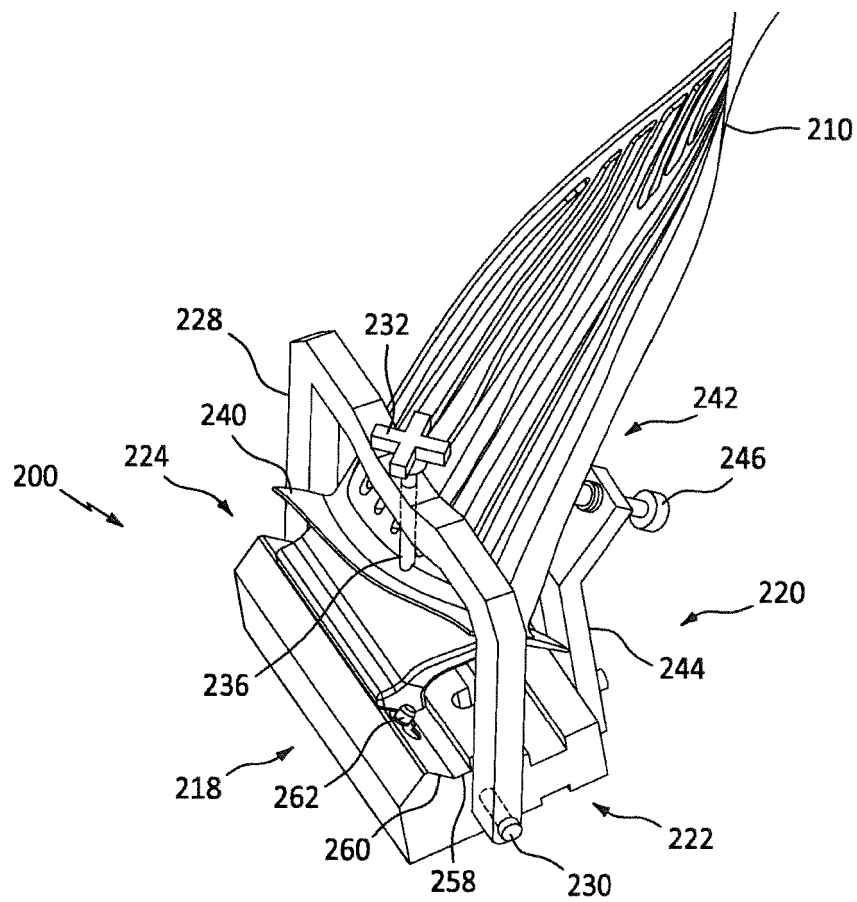


FIG. 10

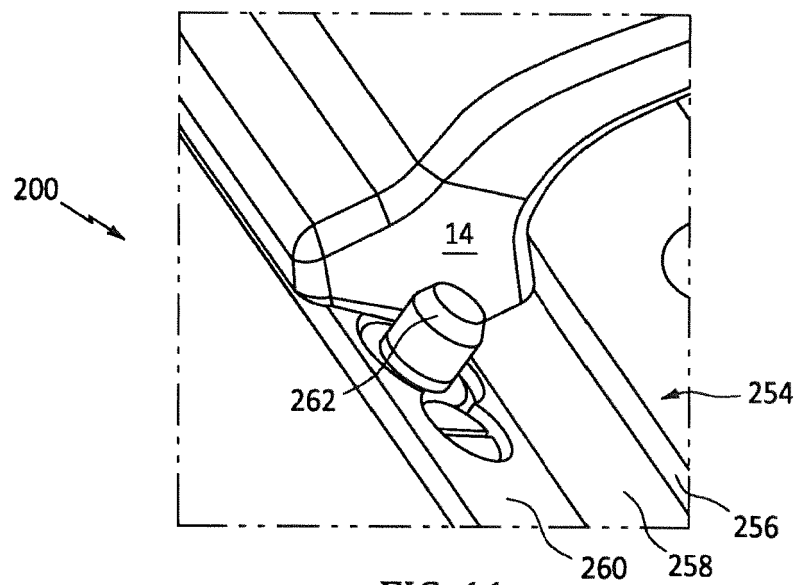


FIG. 11

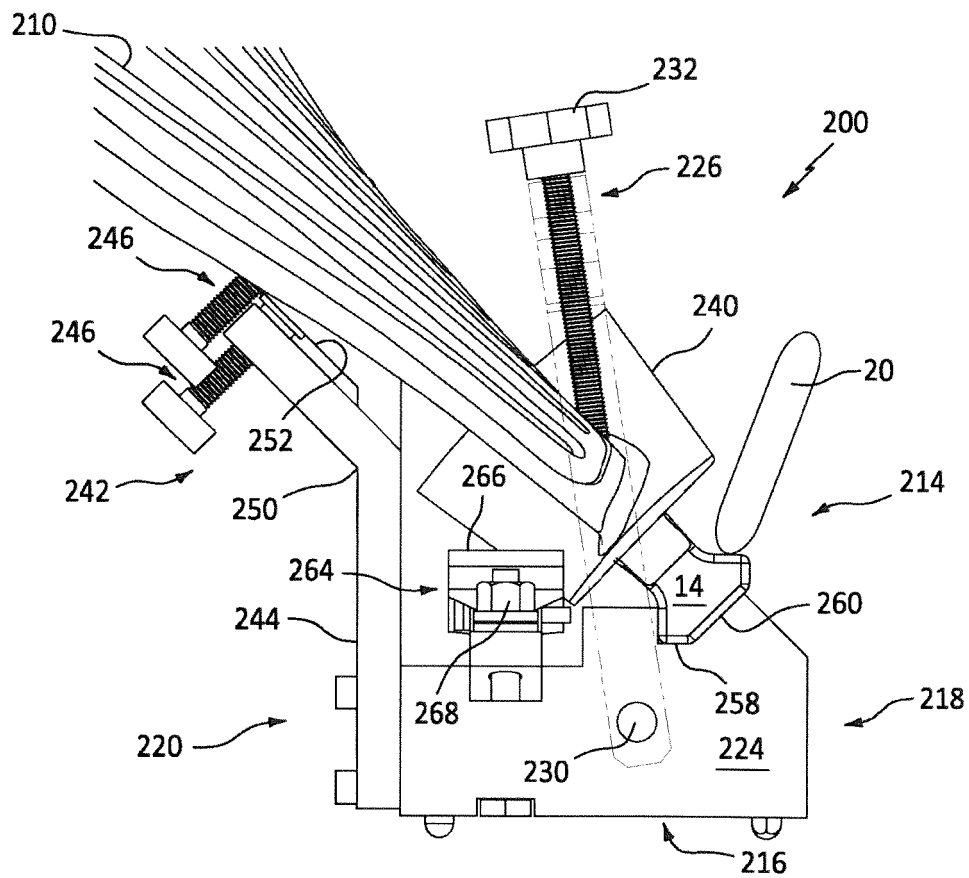


FIG. 12

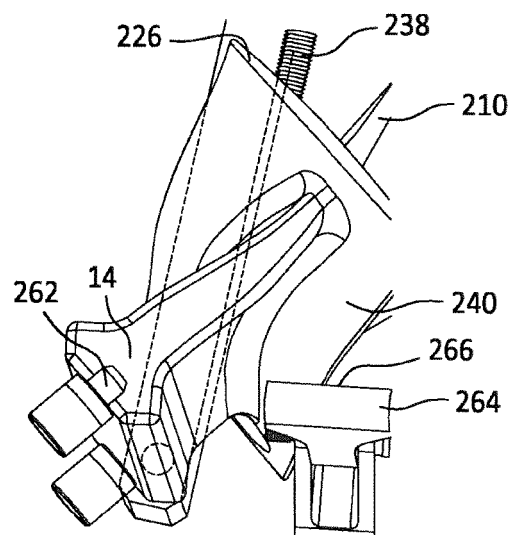


FIG. 13

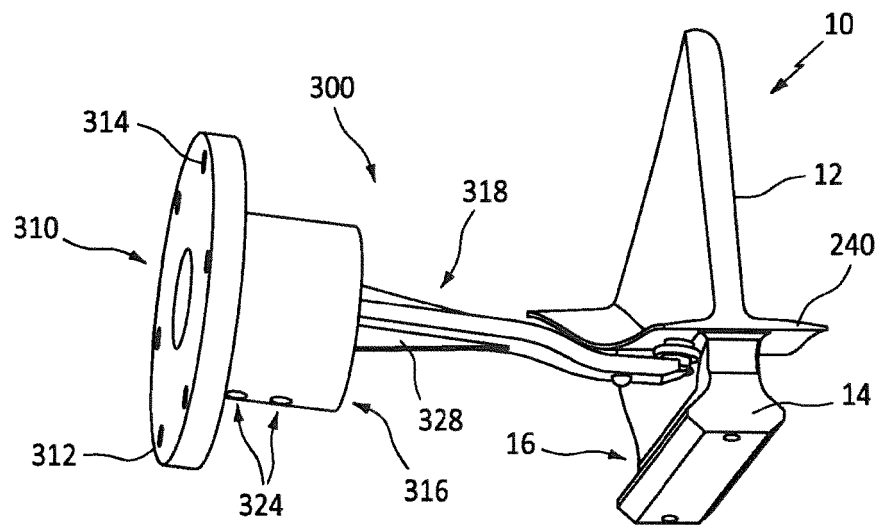


FIG. 14

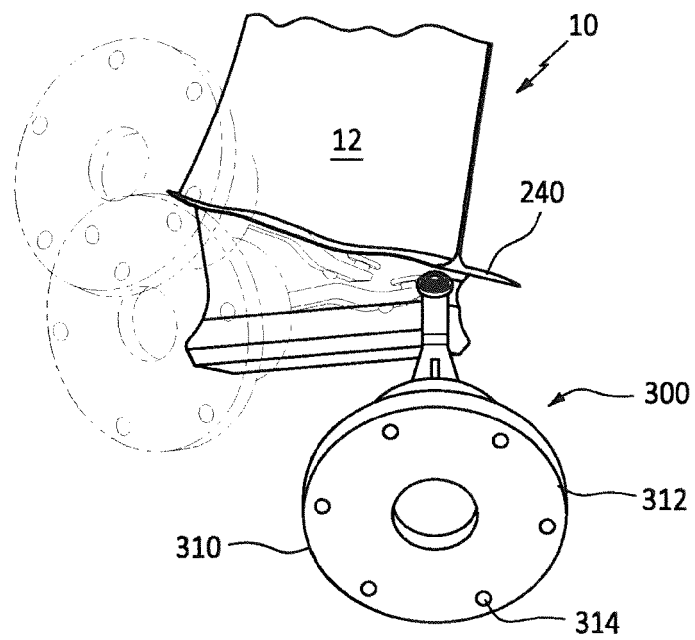


FIG. 15

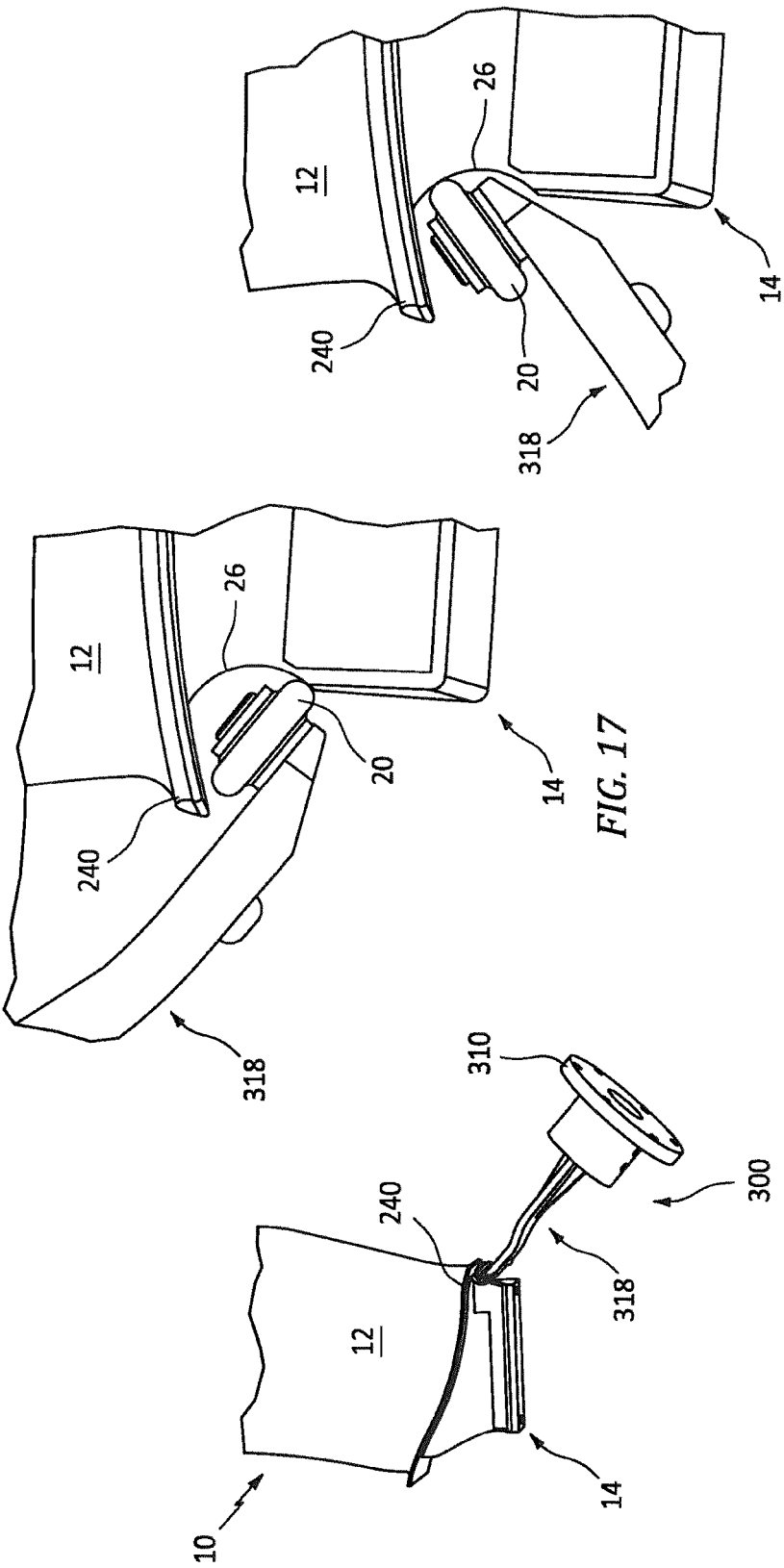


FIG. 18

FIG. 17

FIG. 16

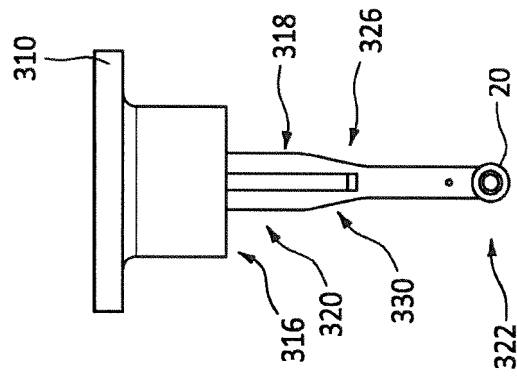


FIG. 19

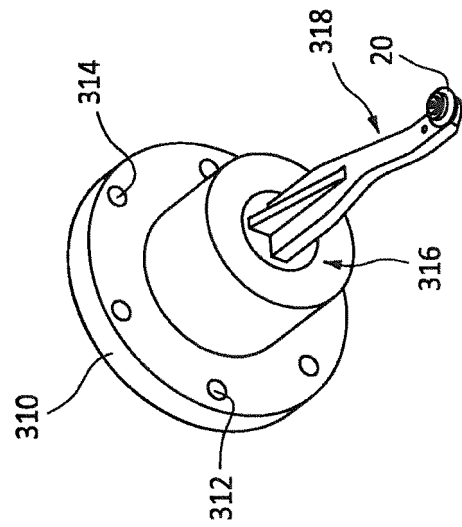


FIG. 20

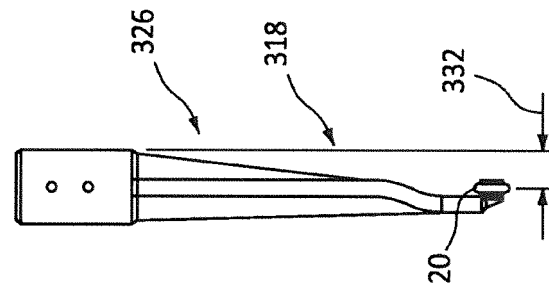


FIG. 21

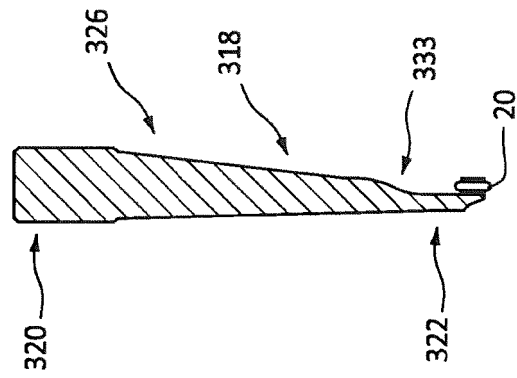


FIG. 22

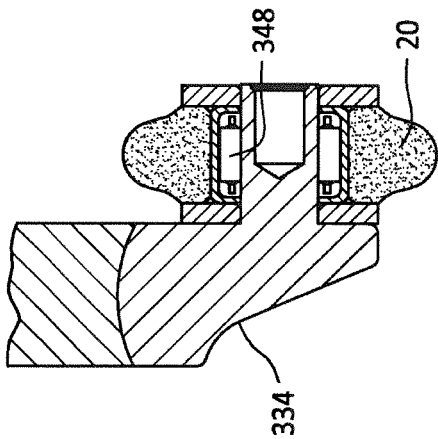


FIG. 26

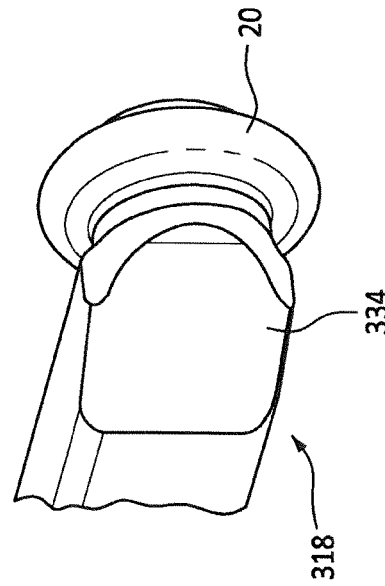


FIG. 25

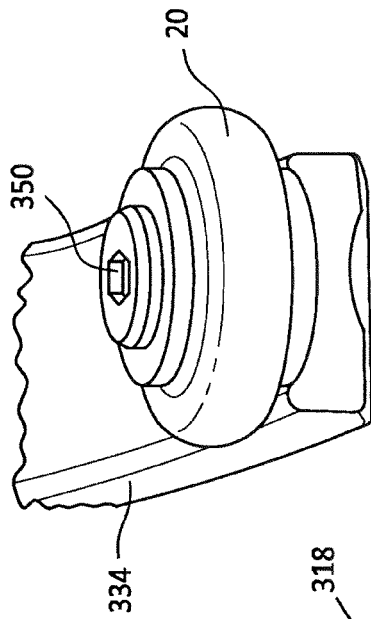


FIG. 24

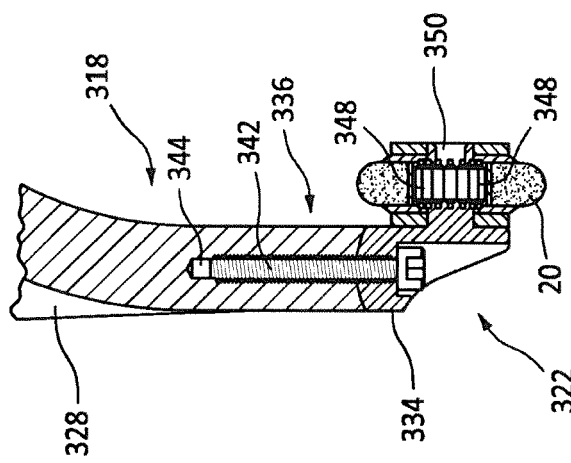


FIG. 23

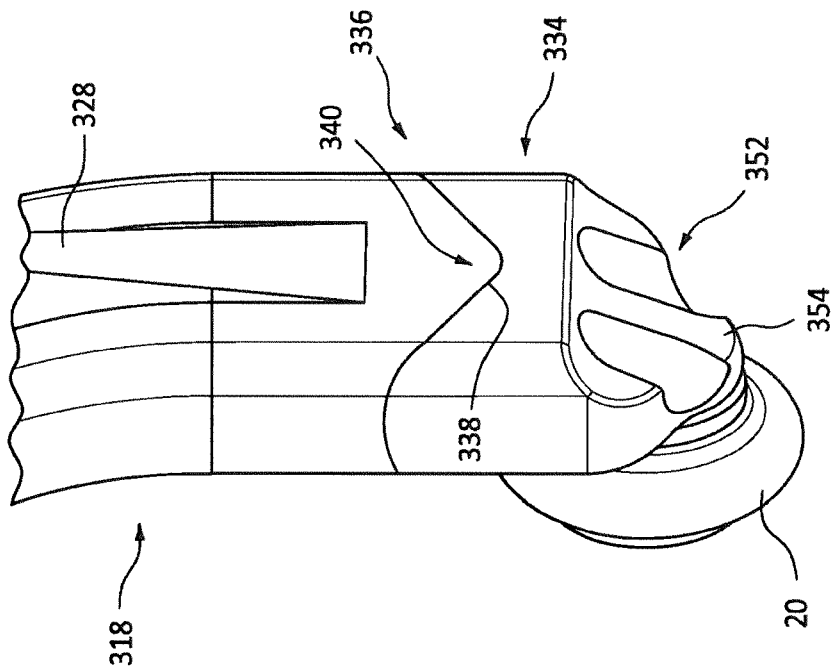


FIG. 27

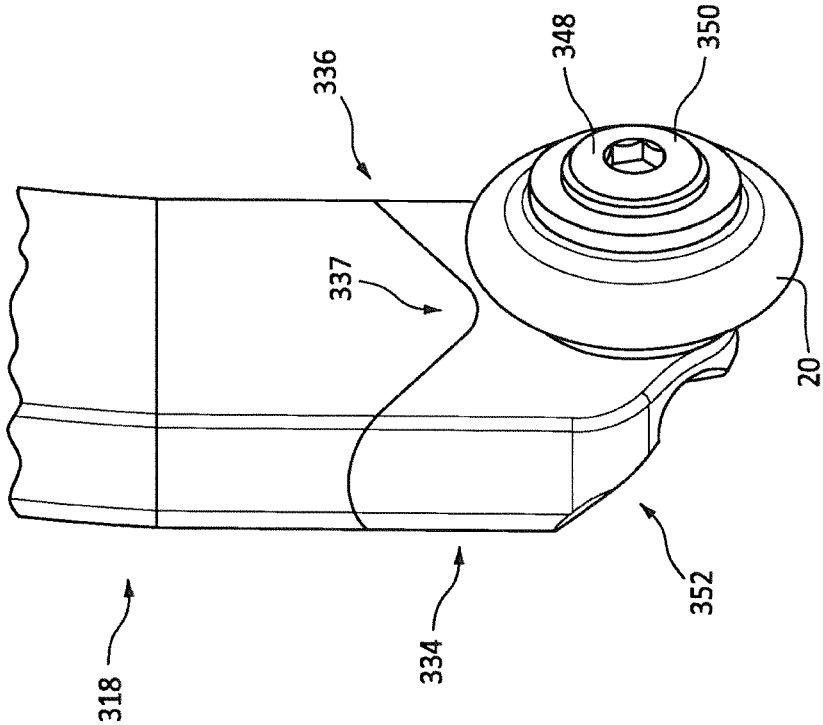


FIG. 28

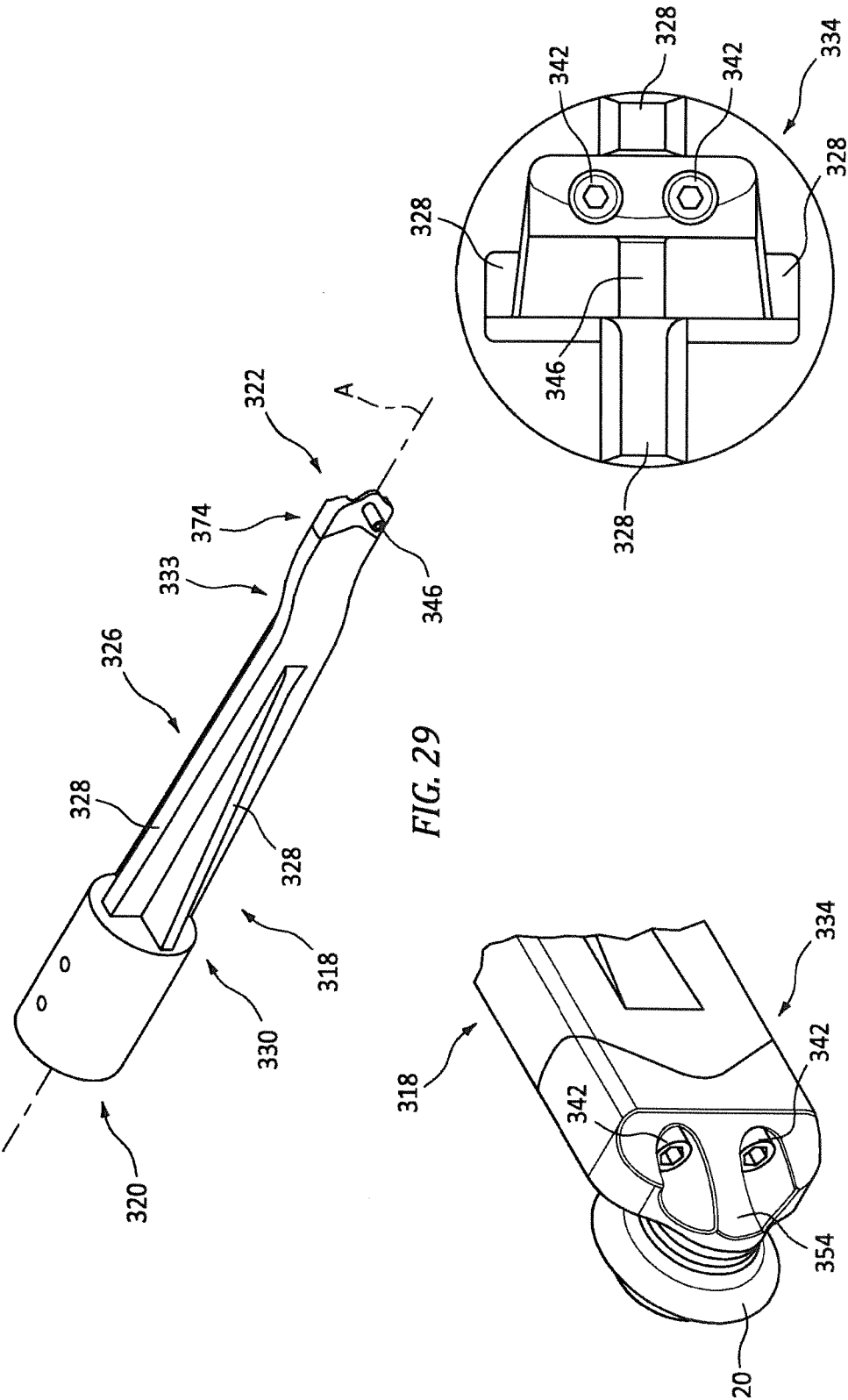


FIG. 31

FIG. 30

FIG. 29



EUROPEAN SEARCH REPORT

Application Number

EP 24 21 3100

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2018/171447 A1 (HAWKES JUSTIN R [US] ET AL) 21 June 2018 (2018-06-21) * paragraphs [0048], [0052]; figures 2,4 *	1-15	INV. B24B39/00 B24B39/04 B24B39/06
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A	US 2012/204390 A1 (PREVEY MICHAEL [US] ET AL) 16 August 2012 (2012-08-16) * figure 9 *	3	
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			B24B
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
Munich		27 March 2025	Koller, Stefan
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			
T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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27-03-2025

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82