(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
9 April 2015 (09.04.2015)

WIPO | PCT

(10) International Publication Number
WO 2015/050657 A1

(51) International Patent Classification:
G01B 11/14 (2006.01) *G01B 5/14* (2006.01)

(21) International Application Number:
PCT/US2014/053635

(22) International Filing Date:
2 September 2014 (02.09.2014)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
14/043,878 2 October 2013 (02.10.2013) US

(71) Applicant: **SIEMENS ENERGY, INC.** [US/US]; 4400 Alafaya Trail, Orlando, Florida 32826-2399 (US).

(72) Inventors: **SILIETI, Mahmood K.**; 16619 Tudor Grove Drive, Orlando, Florida 32828 (US). **HINES, Kevin L.**; 28014 County Road 46A, Sorrento, Florida 32776 (US). **CHEHAB, Abdullatif M.**; 2273 Lake View Avenue, Chuluota, Florida 32766 (US).

(74) Agents: **RYAN, Daniel, J.** et al.; Siemens Corporation - Intellectual Property Dept., 3501 Quadrangle Blvd., Ste 230, Orlando, FL 32817 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) Title: TURBINE BLADE-MOUNTED SENSOR FIXTURE FOR TIP GAP MEASUREMENT

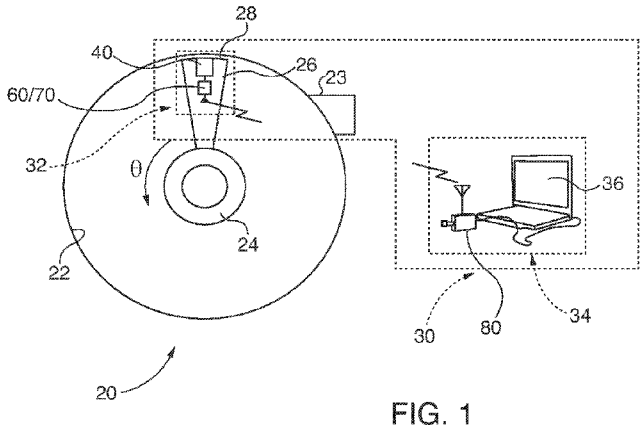


FIG. 1

(57) Abstract: Turbine blade tip clearance is measured in a fully assembled turbine casing by mounting a non-contact displacement probe or sensor on a turbine blade that generates data indicative of sensor distance from the turbine casing that circumferentially surrounds the blade. The sensor is mounted on the blade with a sensor fixture, which includes a clamping mechanism and a sensor retention mechanism that retains and calibrates the sensor by selective movement of the sensor relative to the retention mechanism. Variations in sensor distance data are recorded when the turbine is operated in turning gear mode. Blade rotational position data are collected by a rotational position sensor. A data processing system correlates the distance and rotational position data with localized blade tip gap at angular positions about the turbine casing circumference. This method and apparatus facilitate assessment of turbine casing deformation impact on blade tip clearance and rotor/casing alignment.

WO 2015/050657 A1

TURBINE BLADE-MOUNTED SENSOR FIXTURE FOR TIP GAP MEASUREMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of co-pending, commonly owned at time of filing, United States utility patent application entitled "IN-SITU BLADE-MOUNTED TIP GAP MEASUREMENT FOR TURBINES", filed herewith, on October 2, 2013 and assigned serial number 14/043,913 Siemens files 2013P07579US/2013E00849US (Siemens 203), which is incorporated by reference herein.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The invention relates to in-situ measurement of steam or gas turbine blade tip gap between rotating blades and the circumscribing turbine casing ring segment. More particularly, embodiments of the invention relate to in-situ blade tip gap measurement by mounting a radially oriented displacement sensor directly on a turbine blade while in-situ within an industrial gas turbine and rotating the rotor so that the blade sweeps at least a portion of the circumscribing turbine casing ring segment in either the compressor or hot gas turbine sections. In other embodiments of the invention the entire circumference of the circumscribing casing ring segment is swept by rotating the rotor while the industrial gas turbine is operated in turning gear mode.

[0004] 2. Description of the Prior Art

[0005] During assembly and at periodic times throughout the life of a gas turbine blade tip clearances must be measured. Proper tip clearance enables better efficacy of gas turbines and lowers harmful emissions. To date there are ways of measuring tip clearances, but the methods requiring the removal of the upper casing that circumscribes

the turbine blade tips during measurement, limited number of inspection points, or take a relatively long time to complete.

[0006] There are typically two known common methods for measuring blade tip clearances. In the first method the measurement of tip clearance is typically accomplished by removing the turbine or compressor case upper half to provide access to the blades. Shims are then inserted between the blades tips and the flow path side or ring segments of the lower case at the horizontal joint. Measurements are typically taken at the leading and trailing edge sides of the blade tips for every blade. These measurements are referred to as half shell measurements. This method provides very little accuracy or reproducibility because the lower case tends to change shape without the upper case in place. Also, the half shell measurement locations are not necessarily representative of the local case shape at all angular rotational positions about the entire rotational surface swept by the turbine blade.

[0007] The second known common method for measuring blade tip clearances is by opening an inspection port in the side of the engine that is aligned with the blade path. A contact or non-contact probe is inserted into the port to measure the distance of the blade tip from the gas path side of the case or ring segments. There are a limited number of these inspection ports oriented about the turbine casing. Therefore only data from select rows and cord positions can be obtained. Furthermore, as noted above in the description of the first known inspection method the inspection locations may not be representative of the casing shape about the entire rotational circumference of the turbine. In some spots, due to casing shape disparities, there may be varying tip gap.

[0008] Thus, a need exists for a method to measure turbine blade tip clearances in-situ within an assembled turbine without removing part of the turbine casing that circumscribes the blade tips.

[0009] A need also exists for a method to measure turbine blade tip clearances in-situ within an assembled turbine casing, so that localized blade tip gap differences can be identified and measured.

[0010] An additional need exists for a method to determine whether the turbine rotor assembly is aligned within its circumscribing turbine casing, so that alignment can be adjusted to assure rotor rotational axis concentricity within the casing. For example, so that turbine vane carriers are centered to the rotor during alignment verification.

SUMMARY OF THE INVENTION

[0011] Accordingly, an object of the invention is to measure turbine blade tip clearances in-situ within an assembled turbine without removing part of the turbine casing that circumscribes the blade tips.

[0012] It is also an object of the invention to measure turbine blade tip clearances in-situ within an assembled turbine casing, so that localized blade tip gap differences can be identified and measured.

[0013] An additional object of the invention is to determine whether the turbine rotor assembly is aligned within its circumscribing turbine casing, so that alignment can be adjusted to assure rotor rotational axis concentricity within the casing, including but not limited to turbine vane carriers/rotor centering during alignment verification.

[0014] These and other objects are achieved in accordance with embodiments of the present invention by using the blade (not the case) as the reference measurement location without removing the cover as is traditionally done. This enables the measurement of the tip clearance of a particular blade along the entire path it makes during one or more revolutions in the engine on turning gear. Embodiments of this method of tip clearance measurement include a non-contact displacement sensor coupled with a data acquisition

system to record the measured displacement between the blade and the corresponding circumscribing turbine casing (e.g., the gas path side of the case or the ring segments). In addition, each displacement measurement is related to a an angular rotational clock position around the rotor by a sensor that monitors the rotor rotational position or any other sensor location that is coupled to the turbine. The gap measurement displacement and data acquisition system are coupled to the specified blade using a sensor fixture that is clamped to the blade. Displacement and rotational position data collected are streamed wirelessly in real time during measurement. This method and apparatus provide an accurate and cost effective solution for accessing turbine casing deformation impact on blade tip clearance and rotor/casing alignment.

[0015] More particularly, embodiments of the invention feature a method for measuring gas turbine blade tip and turbine casing radial clearance gap in a gas turbine with a rotatable rotor having a turbine blade with a radially outwardly projecting tip in opposed spaced relationship with a circumscribing turbine casing, defining a gap there between. A non-contact displacement sensor that is capable of generating a displacement data set and a sensor fixture including a sensor retention mechanism for calibrating the displacement sensor position and a clamp mechanism for clamping the fixture to the turbine blade are provided to practice the method. The displacement sensor is coupled to the sensor fixture. The sensor fixture is coupled to the turbine blade with the clamp mechanism, so that the non-contact displacement sensor is capable of generating a data set of displacement relative to the circumscribing turbine casing. The displacement sensor position relative to the blade tip is calibrated by moving the displacement sensor within the sensor retention mechanism. A rotor rotational position sensor is coupled to the turbine. The rotor is rotated so that the turbine blade tip sweeps at least a portion of the circumscribing turbine casing while generating the displacement data set with the non-contact displacement sensor and a rotational position data set with the rotational position sensor. The displacement and rotational position data sets are acquired with a data acquisition system that is coupled to the displacement and rotational position sensors. Blade tip and circumscribing turbine casing radial clearance gap relative to

rotational position is correlated with the displacement and rotational data sets in a data analyzer system that is coupled to the data acquisition system.

[0016] Other embodiments of the invention feature a system for measuring gas turbine blade tip and turbine casing radial clearance gap in a gas turbine having a rotatable rotor, a turbine blade coupled to the rotor with a radially outwardly projecting tip in opposed spaced relationship with a circumscribing turbine casing, defining a gap there between. The system comprises a non-contact displacement sensor that is capable of generating a data set of displacement relative to a circumscribing turbine casing when the sensor is coupled to a turbine blade. The non-contact displacement sensor is coupled to a sensor fixture having a sensor retention mechanism for retaining and calibrating the displacement sensor by selected movement therein relative to a blade tip, and a clamp mechanism for clamping the fixture to a turbine blade. A rotor rotational position sensor is coupled to the turbine that is capable of generating data set of blade rotational position. The system has a data acquisition system that is coupled to the displacement and rotational position sensors, for acquiring the displacement and rotational position data sets during rotor rotation as the turbine blade tip sweeps at least a portion of the circumscribing turbine casing when the sensor fixture is clamped to the turbine blade. A data analyzer system, coupled to the data acquisition system, correlates, with the displacement and rotational data sets, the blade tip and circumscribing turbine casing radial clearance gap relative to rotational position.

[0017] Additional embodiments of the invention feature a sensor fixture for coupling a sensor to a turbine blade, comprising a clamp base; a clamp screw coupled to the clamp base, for coupling a turbine blade to the clamp base; and a sensor retention mechanism coupled to the clamp base, for retaining and calibrating a sensor by selective movement of the sensor relative to the retention mechanism.

[0018] The objects and features of the present invention may be applied jointly or severally in any combination or sub-combination by those skilled in the art.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] The teachings of the invention can be readily understood by considering the following detailed description in conjunction with the accompanying drawings, in which:

[0020] FIG. 1 is an elevational schematic view of an embodiment of a turbine tip gap clearance measurement system of the invention coupled to a turbine, including a blade mounted instrument system with a probe system and a data acquisition system that are communicatively coupled to a data processing system outside the turbine via a wireless communication system;

[0021] FIG. 2 is a detailed schematic view of an embodiment of a probe system, including a non-contact displacement sensor, coupled to a turbine blade;

[0022] FIG. 3 is an elevational schematic view of another embodiment of a turbine tip gap clearance measurement system of the invention coupled to a turbine, including a blade mounted instrument system with a probe system and a data acquisition system that are communicatively coupled to a data processing system outside the turbine via a portable data storage device transferred from the blade mounted instrument system to a data processing system interface for downloading to the data processing system personal computer;

[0023] FIG. 4 is an elevational schematic view of another embodiment of a turbine tip gap clearance measurement system of the invention coupled to a turbine, including a blade mounted instrument system with a probe system and a data acquisition system that are communicatively coupled to a data processing system outside the turbine via a cable;

[0024] FIG. 5 is a detailed elevational schematic view of an embodiment of a retaining strap for mounting a probe system of the invention to a turbine blade, having mating hook and loop fasteners;

[0025] FIG. 6 is a detailed elevational schematic view of an embodiment of a retaining clamp for mounting a probe system of the invention to a turbine blade, having opposed plates that are compressively coupled to a turbine blade circumference by screws;

[0026] FIG. 7 is a perspective elevational view of a turbine blade row including an embodiment of a blade mounted instrument of the invention that is coupled to a turbine blade with an embodiment of a sensor fixture of the present invention;

[0027] FIG. 8 is a perspective elevational view of the embodiment of a blade mounted instrument and sensor fixture of FIG. 7 taken from the opposite side of the blade row;

[0028] FIG. 9 is a detailed perspective view of the sensor fixture of FIG. 8, showing alignment of the non-contact sensor probe with the blade tip;

[0029] FIG. 10 is an elevational perspective view of another embodiment of a sensor fixture and sensor of the present invention coupled to a turbine blade;

[0030] FIG. 11 is an elevational perspective view of the sensor fixture of FIG. 10, showing attachment of an alignment bracket for calibrating the sensor position relative to the turbine blade tip; and

[0031] FIG. 12 is a side elevational view of the sensor fixture and alignment bracket of FIG. 11, showing sensor calibration alignment flush with the blade tip, prior to removal of the alignment bracket.

[0032] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures.

DETAILED DESCRIPTION

[0033] After considering the following description, those skilled in the art will clearly realize that the teachings of the invention can be readily utilized in methods and apparatus for in-situ measurement of steam or gas turbine blade tip gap between rotating blades and the circumscribing turbine casing (e.g., the ring segments or gas paths defined within the casing). using the blade (not the case) as the reference measurement location without removing the cover as is traditionally done. This enables the measurement of the tip clearance of a particular blade along the entire path it makes during one or more revolutions in the engine on turning gear. The measurement system can be moved from blade to blade so that tip gap information can be obtained for a plurality of or all of the blades about their full 360 degree rotational sweep, including critical measurements at the six o-clock or bottom casing location that is susceptible to transient and permanent thermal distortion during engine operation. By performing the tip gap measurements on a fully assembled turbine casing the gathered information is indicative of the actual clearances experienced by an operational turbine, including any potential mechanical or thermal distortions imparted on the casing structure after its assembly. Also, after sufficient cool down of an in-service engine, pre-rebuild tip gap measurements can be obtained for service diagnostic evaluation and to obtain pre-rebuild baseline clearance information suitable for “before” and “after” rebuild evaluation and documentation.

[0034] Embodiments of this method of tip clearance measurement and the measurement system include a non-contact displacement sensor within a probe that is coupled with a data acquisition system to record the measured displacement between the blade and the corresponding circumscribing turbine casing (e.g., the gas path side of the case or the ring segments). In addition, an angular position sensor, coupled to the turbine or a blade is used to relate each measurement to an angular rotational clock position around the rotor

by measuring the blade orientation with respect to a reference position. The gap measurement displacement and data acquisition system are coupled to one or more of the blades using a mechanical, magnetic, or adhesive gripping mechanism. Embodiments of the invention include sensor fixtures that clamp a non-contact displacement sensor or any other type of sensor or other object to a turbine blade. The sensor fixture also includes a sensor retention mechanism for retaining and calibrating a sensor by selective movement of the sensor relative to the retention mechanism. Data collected can be either stored the data acquisition system internal storage, removable media, or can be streamed wirelessly in real time during measurement. Data collected can also be communicated via a direct cable connection. A data analyzer coupled to the data acquisition system correlates blade tip and circumscribing turbine casing radial clearance gap relative to rotational position with the displacement and rotational data sets. This method and apparatus provide an accurate and cost effective solution for accessing turbine casing deformation impact on blade tip clearance and rotor/casing alignment.

[0035] FIGs. 1 and 2 show schematically a gas turbine 20, with a turbine casing having an inner circumferential ring segment 22 that defines an inner diameter and an access port 23. Rotor 24 rotates within the turbine 20. Affixed to the rotor 24 are a plurality of rows of turbine blades 26 that are designated B_1-B_N. Only a single blade row is schematically shown in FIG. 1. As a blade 26 rotates with the rotor 24, it defines a rotational displacement θ; its blade tip 28 sweeps the circumscribing inner circumferential ring segment 22. Radial separation between the mutually opposed and spaced blade tip 28 and the ring segment 22 inner diameter is designated by the gap that is labeled “g” in the figures herein.

[0036] The blade tip clearance system 30 embodiment shown in FIGs. 1 and 2 comprises a blade mounted instrument 32 that is communicatively coupled to a blade tip clearance data analyzer system 34. In this embodiment communication is established via wireless communication system, for example one utilizing Bluetooth communications protocol.

The data analyzer system 34 may be incorporated into a personal computer 36. Details of the blade clearance system 30 architecture and function are further described.

[0037] The blade mounted instrument 32 includes a displacement probe system 40, which as shown in FIGs. 1 and 2 is a non-contact type displacement probe having at least one photonic energy transmitter 42 and a corresponding receiver 44 of known construction. FIG. 2 shows a probe 40 having an arrayed pair of transmitters and receivers. In this embodiment the transmitted and received photonic energy is in the visible spectrum. The displacement probe 40 generates a displacement data set of relative distance between the probe and the circumscribing turbine casing circumferential ring 22. A rotor rotational position acquisition system sensor 60 is also coupled to the blade 26 in order to sense the rotor/corresponding blade's rotational position θ and generate a rotational position data set. The rotational position sensor 60 is of known construction, exemplary embodiments of which may include known tilt, gyroscopic or localized triangulated GPS-type sensors. Alternatively the rotational position sensor function may be performed by an existing turbine rotor rotational position sensor.

[0038] The blade mounted displacement probe system 40 and the rotor/blade rotational system sensor 60 are coupled to data acquisition module 70 that acquires the displacement and rotational position data sets. While the data acquisition module 70 is shown coupled to the turbine blade 26 and receives both the displacement and rotational position data sets, alternative locations and data feed configurations are possible in other embodiments. For example, the sensors 40 and 60 may be coupled jointly or severally to a wireless communication module that in turn communicates with a non-blade mounted data acquisition module. Similarly the data acquisition module function may be divided into separate components that receive separate positional or displacement data sets from the respective sensors 40 and 60.

[0039] The data acquisition module 70 sends the displacement and rotational position data sets to the data analyzer system 34 via wireless Bluetooth communication with the

data analyzer system interface 80. The data analyzer system 34 includes the data analyzer interface 80 and the personal computer 36; the latter correlates blade tip and circumscribing turbine casing radial clearance gap relative to rotational position with the displacement and rotational data sets received from the data acquisition module 70. Blade tip gap g information and relative rotational position in the data analyzer system 34 is available for further analysis, including by way of example relative concentric alignment of the rotor, rotor blades, turbine vanes and the turbine casing inner diameter, concentricity of the turbine casing itself and identification of potential localized wear patterns within the turbine casing lining. If multiple displacement probes 40 are utilized across the axial length of the blade tip 28 annular patterns, rather than just circular patterns of blade tip gap g about the turbine casing circumference can be acquired and analyzed.

[0040] As shown in FIG. 3 by the double arrow the blade mounted instruments 32 can be installed and removed via a turbine access port 23 or manway, or by removing a section of the turbine external housing that does not circumscribe the blade tips 28. Similarly, if a wireless communication system is not utilized between the data acquisition module 70 and the data analyzer system 34, a portable memory device may be incorporated into the data acquisition module and to store the acquired rotational and/or displacement data sets. The memory device is removed after data acquisition by the blade tip clearance system 30 and subsequently transported as shown schematically by the double lines for coupling to the data analyzer interface 80' and for subsequent downloading of the data sets. Alternatively, as shown in FIG. 4, the data acquisition module 70 may be communicatively coupled to the data analyzer interface 80" by a physical cable 82 routed through an access port 23. The cable 82 has sufficient length to be wrapped around the turbine rotor 24.

[0041] As previously noted the blade mounted instruments 32 are coupled or otherwise affixed to the blade 26 so that they do not inadvertently drop within the turbine interior during a blade gap measurement procedure. As shown in FIG. 5, a probe 40 of the blade

mounted instrument is coupled to the blade 26 by a hook and loop fastened strap 50 that is circumferentially wrapped about the blade. In FIG. 6 the probe 40 is coupled to the blade 26 by a retaining clamp 50', having opposed plates that are compressively coupled to a turbine blade circumference by screws.

[0042] The invention also includes embodiment of sensor fixtures that facilitate mounting of the blade gap measurement instrumentation or other types of sensors or instruments to a turbine blade. FIG. 7-9 show a first embodiment of a sensor fixture 450, which comprises a clamp base 452 with a generally C-shaped profile for slidable insertion and capture of a turbine blade 26 therein. A clamping mechanism in the form of a clamp screw 458 is tightened to clamp the blade within the clamp base 452. The optical sensor 40 has a threaded exterior portion 46 that mate with corresponding threads formed in an aperture 454 that is defined by the clamp base 452. The aperture 454 functions as a sensor retention mechanism for retaining and calibrating the sensor 40. Calibration is achieved by advancing/moving the sensor 40 outer threads 46 relative to the retention mechanism aperture threads 454 in either direction, so that the sensor is oriented a defined distance from the turbine ring inner circumference 22. Once the sensor 40 is calibrated its desired position relative to the blade tip 28 or the turbine ring inner circumference 22 the screw locking mechanism 546 is tightened to set or fix the sensor and retention mechanism relative positions.

[0043] The blade mounted instrument 232 of FIGs. 8 and 9 comprise a contact displacement probe 240 with a displaceable probe tip 242 that is in contact with the blade circumscribing turbine casing inner diameter surface 22. Physical displacement of probe tip 242, as shown by the double-ended arrow, generates a displacement data set. The blade mounted instrument 232 is coupled to blade 26 by one or more magnets 250. Displacement data generated by the contact displacement probe 240 is gathered by data acquisition module 270 that in turn routes the displacement data to the data analyzer system interface 280 via wireless communication (e.g., Bluetooth) protocols, as previously described. The turbine blade rotational positional data set is generated by the

turbine rotor positional sensor 260 rather than a blade-mounted positional sensor. The rotational positional data set is routed to the data analyzer system 234 by known means, such as a communications cable. The data analyzer system 234 correlates the received displacement and rotational position data sets with blade gap about the turbine casing inner diameter 22 as previously described.

[0044] FIGs. 10-12 show another sensor fixture 550 embodiment. The sensor fixture 550 has a clamp base 552 with a pair of C-shape profile portions for slidable insertion and capture of a turbine blade therein at two spaced positions along a long axis of the blade with the clamping mechanisms 558. More than two C-profile portions and clamping mechanisms 558 may be utilized. As with the embodiment of FIGs. 7-9, the sensor fixture 550 includes a sensor retention mechanism in the form of a threaded aperture 554 that receives the external threads of the sensor probe 40 and a locking mechanism screw 556 for fixing sensor and sensor retention mechanism relative position. The sensor fixture 550 also has an L-shaped alignment bracket 264 with an alignment track 266 that is selectively coupled to a clamp base track 560 by a track retention screw 268. The track retention screw 268 mates with a corresponding threaded clamp track aperture 262. The alignment bracket 264 is selectively slidable relative to the clamp track 560 and is locked in a desired position by tightening the track retention screw 268. The alignment bracket 264 facilitates aligning the sensor fixture 550 to a fixed position relative to a blade tip 28 prior to tightening the clamping mechanisms 558 to a blade 26 by abutting the alignment bracket alignment surface 270 against the blade tip 28. Then the sensor 40 is calibrated by abutting it against the alignment bracket alignment surface 270 and thereafter tightening the sensor retention mechanism locking screw 556. The sensor 40 is now aligned flush with the blade tip 28, so that the displacement data set can be directly correlated with the blade tip gap g by the data analyzer 34.

[0045] Although various embodiments that incorporate the teachings of the present invention have been shown and described in detail herein, those skilled in the art can readily devise many other varied embodiments that still incorporate these teachings. The

invention is not limited in its application to the exemplary embodiment details of construction and the arrangement of components set forth in the description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having" and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Unless specified or limited otherwise, the terms "mounted," "connected," "supported," and "coupled" and variations thereof are used broadly and encompass direct and indirect mountings, connections, supports, and couplings. Further, "connected" and "coupled" are not restricted to physical or mechanical connections or couplings.

CLAIMS

What is claimed is:

1. A method for measuring gas turbine blade tip and turbine casing radial clearance gap, comprising:

providing a gas turbine with a rotatable rotor having a turbine blade with a radially outwardly projecting tip in opposed spaced relationship with a circumscribing turbine casing, defining a gap there between;

providing a non-contact displacement sensor that is capable of generating a displacement data set;

providing a sensor fixture including a sensor retention mechanism for calibrating the displacement sensor position and a clamp mechanism for clamping the fixture to the turbine blade;

coupling the displacement sensor to the sensor fixture and coupling the sensor fixture to the turbine blade with the clamp mechanism, so that the non-contact displacement sensor is capable of generating a data set of displacement relative to the circumscribing turbine casing;

calibrating the displacement sensor position relative to the blade tip by moving the displacement sensor within the sensor retention mechanism;

coupling a rotor rotational position sensor to the turbine;

rotating the rotor so that the turbine blade tip sweeps at least a portion of the circumscribing turbine casing while generating the displacement data set with the non-contact displacement sensor and a rotational position data set with the rotational position sensor;

acquiring the displacement and rotational position data sets with a data acquisition system that is coupled to the displacement and rotational position sensors; and

correlating blade tip and circumscribing turbine casing radial clearance gap relative to rotational position with the displacement and rotational data sets in a data analyzer system that is coupled to the data acquisition system.

2. The method of claim 1, the non-contact displacement sensor comprising a non-contact optical displacement sensor having a transmitter and a pair of receivers.

3. The method of claim 1, further comprising a wireless communication system coupling the data acquisition system and the data analyzer system.

4. The method of claim 1, the displacement sensor calibration comprising:

aligning the sensor fixture to a fixed position relative to the blade tip with an alignment bracket coupled thereto and maintaining the sensor fixture alignment by tightening the clamping mechanism to the blade;

moving the displacement sensor within the sensor retention mechanism in contact with the alignment bracket; and

locking the displacement sensor position relative in the sensor retention mechanism.

5. The method of claim 4, further comprising aligning the displacement sensor flush with the blade tip with the alignment bracket and thereafter removing the alignment bracket from the sensor fixture.

6. The method of claim 1 further comprising utilizing the blade tip and turbine casing radial gap measurement information to align any one of the rotor, blades or turbine vanes within the turbine and thereafter re-measuring the radial gap to confirm said alignment.

7. A system for measuring gas turbine blade tip and turbine casing radial clearance gap in a gas turbine having a rotatable rotor, a turbine blade coupled to the rotor with a radially outwardly projecting tip in opposed spaced relationship with a circumscribing turbine casing, defining a gap there between, the system comprising:

a non-contact displacement sensor that is capable of generating a data set of displacement relative to a circumscribing turbine casing when the sensor is coupled to a turbine blade;

a sensor fixture having a sensor retention mechanism retaining and calibrating the displacement sensor by selected movement therein relative to a blade tip, and a clamp mechanism for clamping the fixture to a turbine blade;

a rotor rotational position sensor coupled to the turbine that is capable of generating data set of blade rotational position;

a data acquisition system that is coupled to the displacement and rotational position sensors, for acquiring the displacement and rotational position data sets during rotor rotation as the turbine blade tip sweeps at least a portion of the circumscribing turbine casing when the sensor fixture is clamped to the turbine blade; and

a data analyzer system, coupled to the data acquisition system for correlating, with the displacement and rotational data sets, the blade tip and circumscribing turbine casing radial clearance gap relative to rotational position.

8. The system of claim 7, the non-contact displacement sensor comprising a non-contact optical displacement sensor having a transmitter and a pair of receivers.

9. The system of claim 8, the non-contact optical displacement sensor having a threaded portion that mate with a corresponding threaded portion in the sensor retention mechanism; and a screw locking mechanism for fixing displacement sensor and sensor retention mechanism relative position.

10. The system of claim 7, the sensor fixture further comprising:

a clamp base coupled to the retention mechanism and the clamping mechanism;

an alignment bracket selectively coupled to the clamp base for aligning the sensor fixture to a fixed position relative to a blade tip prior to tightening the clamping mechanism to a blade and for calibrating the displacement sensor by abutting it against the alignment bracket.

11. The system of claim 10, the sensor having a threaded portion that mate with a corresponding threaded portion in the sensor retention mechanism; and a screw locking mechanism for fixing displacement sensor and sensor retention mechanism relative

position.

12. A sensor fixture for coupling a sensor to a turbine blade, comprising:

a clamp base;

a clamp screw coupled to the clamp base, for coupling a turbine blade to the clamp base; and

a sensor retention mechanism coupled to the clamp base, for retaining and calibrating a sensor by selective movement of the sensor relative to the retention mechanism.

13. The sensor fixture of claim 12, further comprising a retention mechanism threaded portion for mating with a corresponding sensor threaded portion; and a locking mechanism for fixing sensor and sensor retention mechanism relative position.

14. The sensor fixture of claim 12, further comprising an alignment bracket selectively coupled to the clamp base for aligning the sensor fixture to a fixed position relative to a blade tip prior to tightening the clamping mechanism to a blade and for calibrating the sensor by abutting it against the alignment bracket.

15. The sensor fixture of claim 14, further comprising the alignment bracket and the clamp base having mating slidable track portions for selective sliding adjustment there between and an alignment bracket lock mechanism for fixing alignment bracket and clamp base relative position.

16. The sensor fixture of claim 15, the alignment bracket having a generally L shape comprising an alignment bracket slidable track portion and an alignment surface portion for abutment with a turbine blade tip and the sensor during sensor calibration.

17. The sensor fixture of claim 16, the alignment bracket selectively removable from the clamping mechanism after sensor calibration by uncoupling the alignment bracket lock mechanism there between.

18. The sensor fixture of claim 12, the clamp base having a generally C-shape profile portion for slidable insertion and capture of a turbine blade therein; the clamping mechanism retaining the captured turbine blade in a fixed position.

19. The sensor fixture of claim 18, the clamp base having at least two C-shape profile portions for slidable insertion and capture of a turbine blade therein at two spaced positions along a long axis of the blade with the clamping mechanism.

20. The sensor fixture of claim 19, further comprising an alignment bracket selectively coupled to the clamp base for aligning the sensor fixture to a fixed position relative to a blade tip prior to tightening the clamping mechanism to a blade and for calibrating the sensor by abutting it against the alignment bracket.

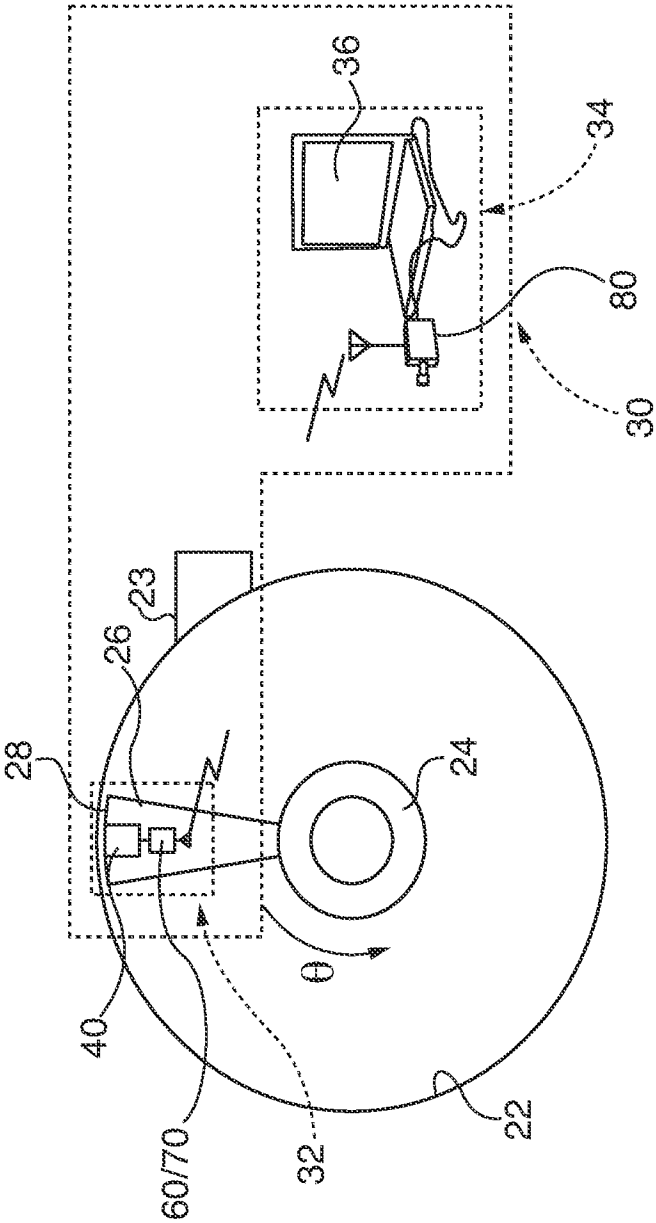


FIG. 1

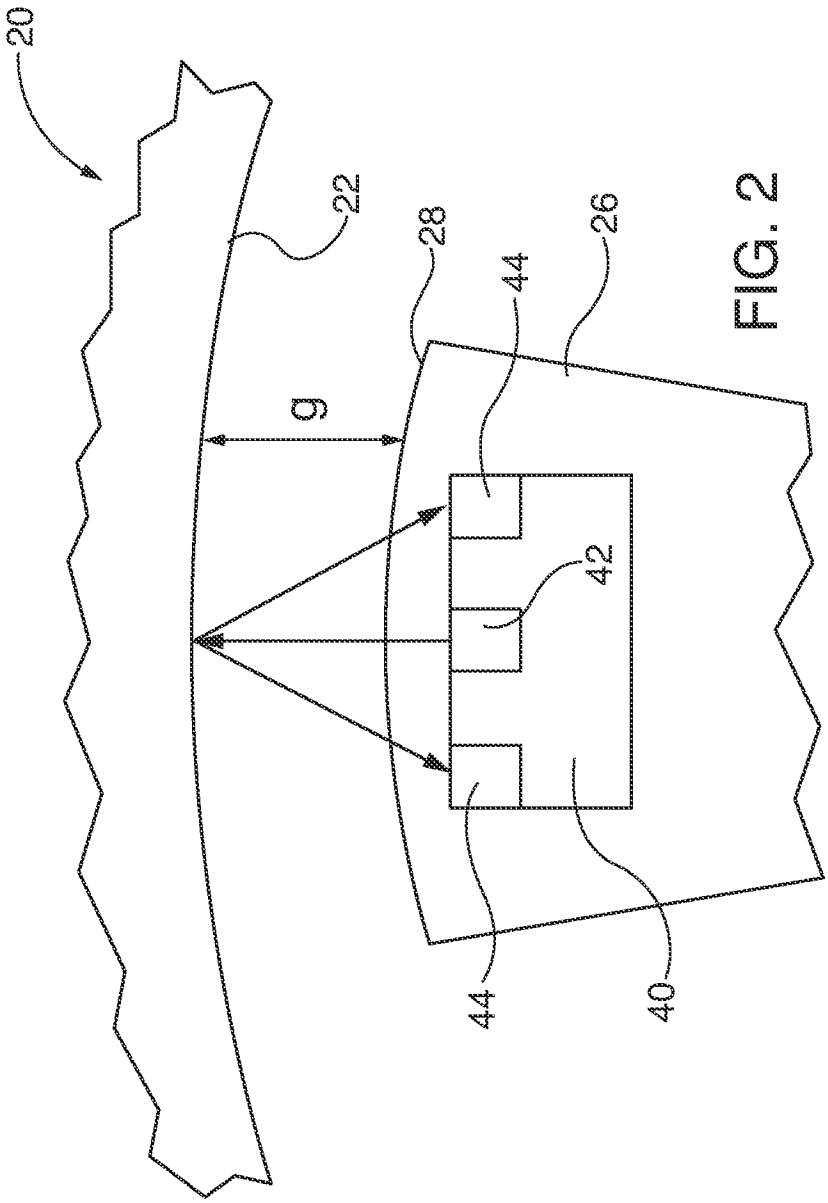


FIG. 2

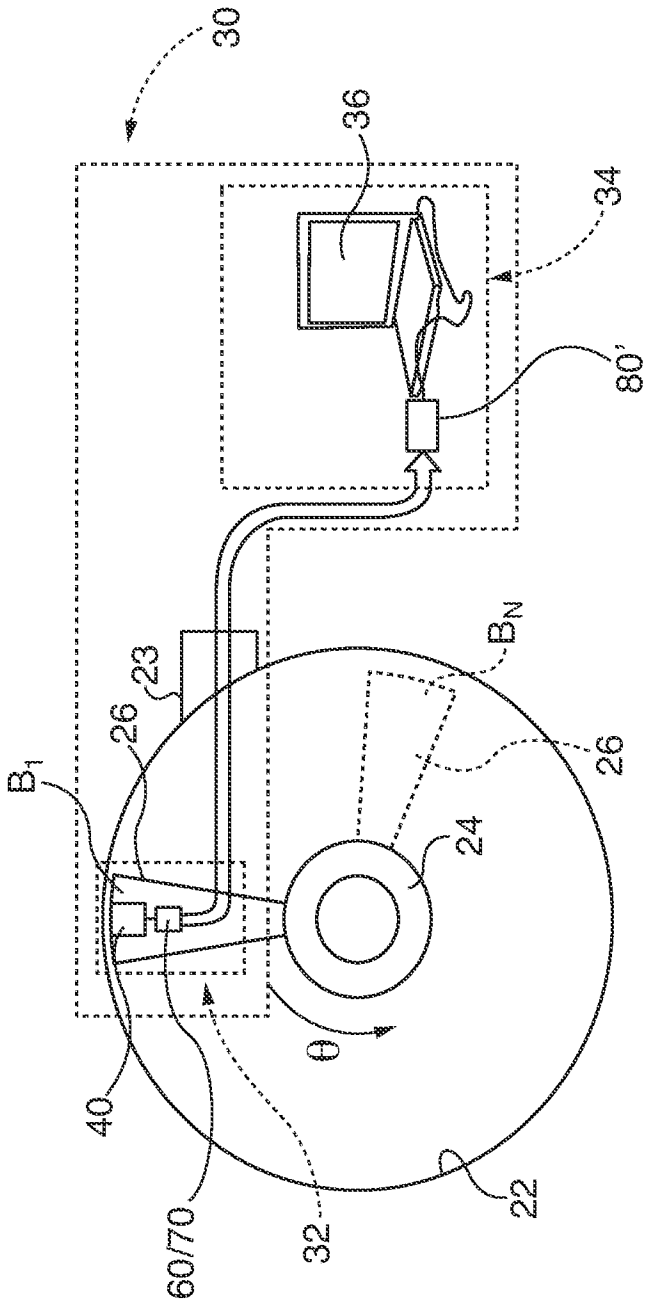


FIG. 3

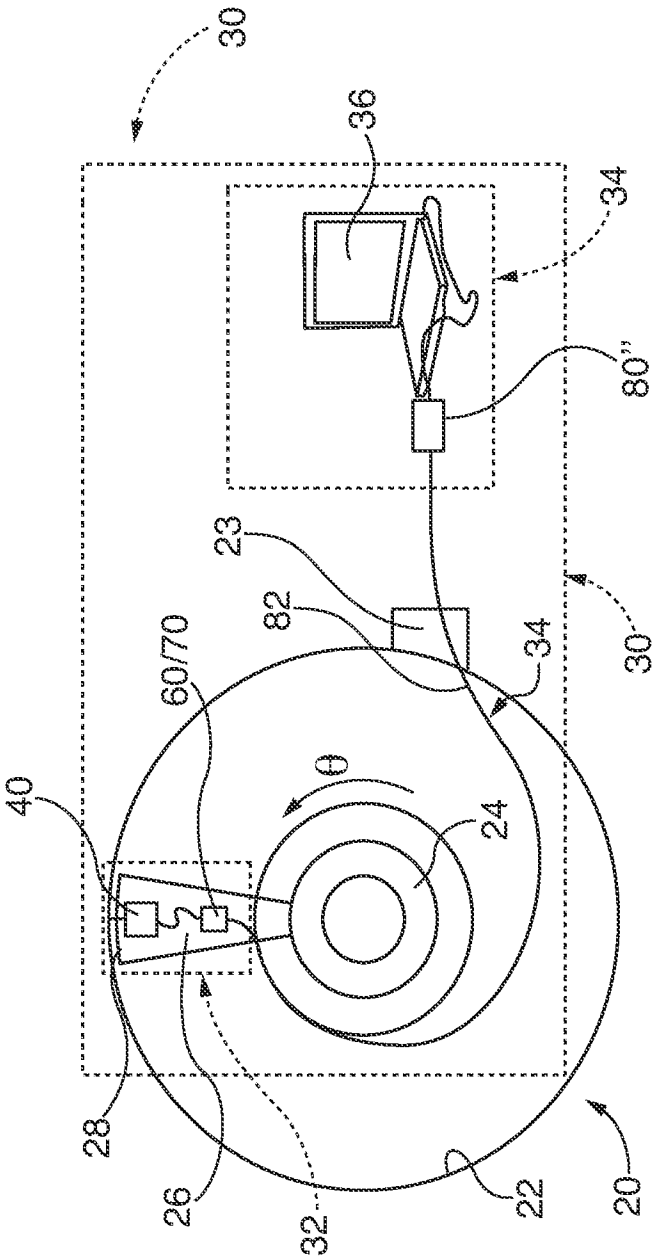


FIG. 4

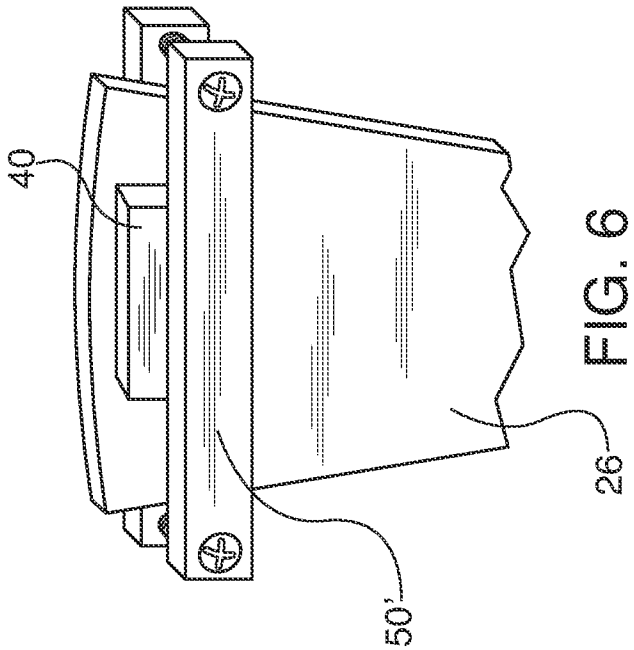


FIG. 6

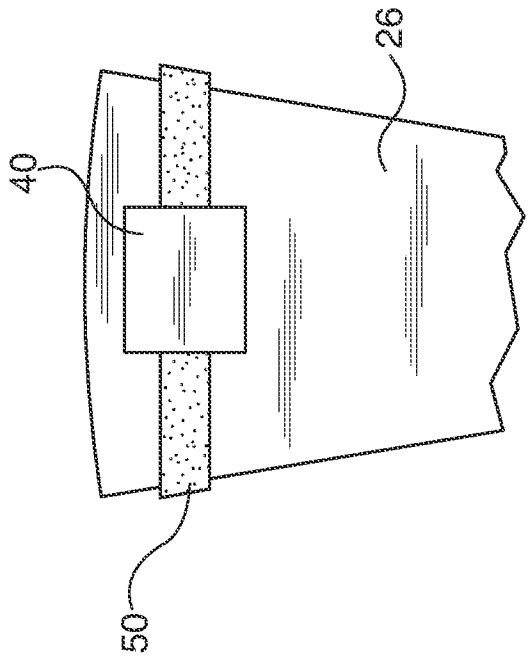


FIG. 5

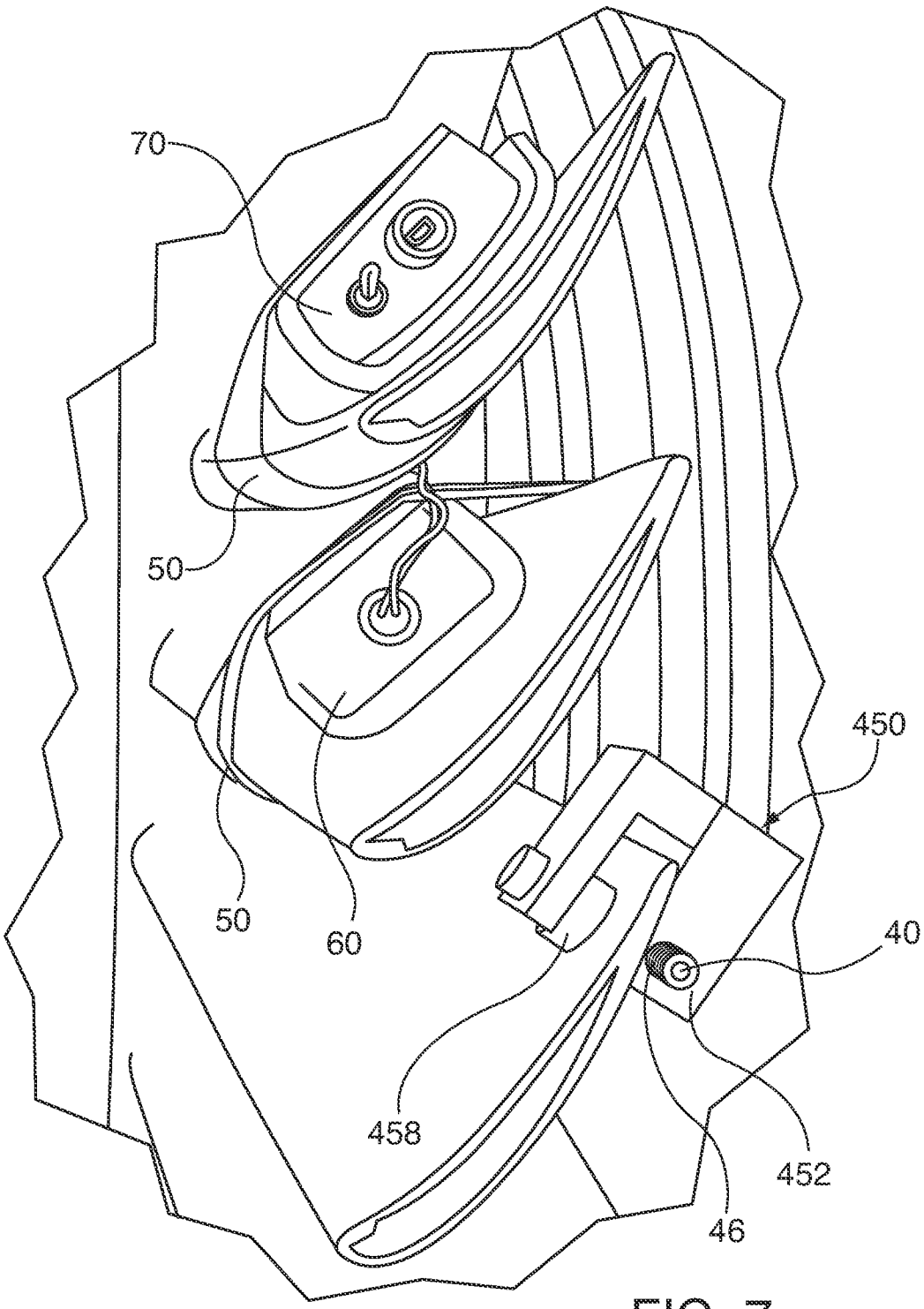


FIG. 7

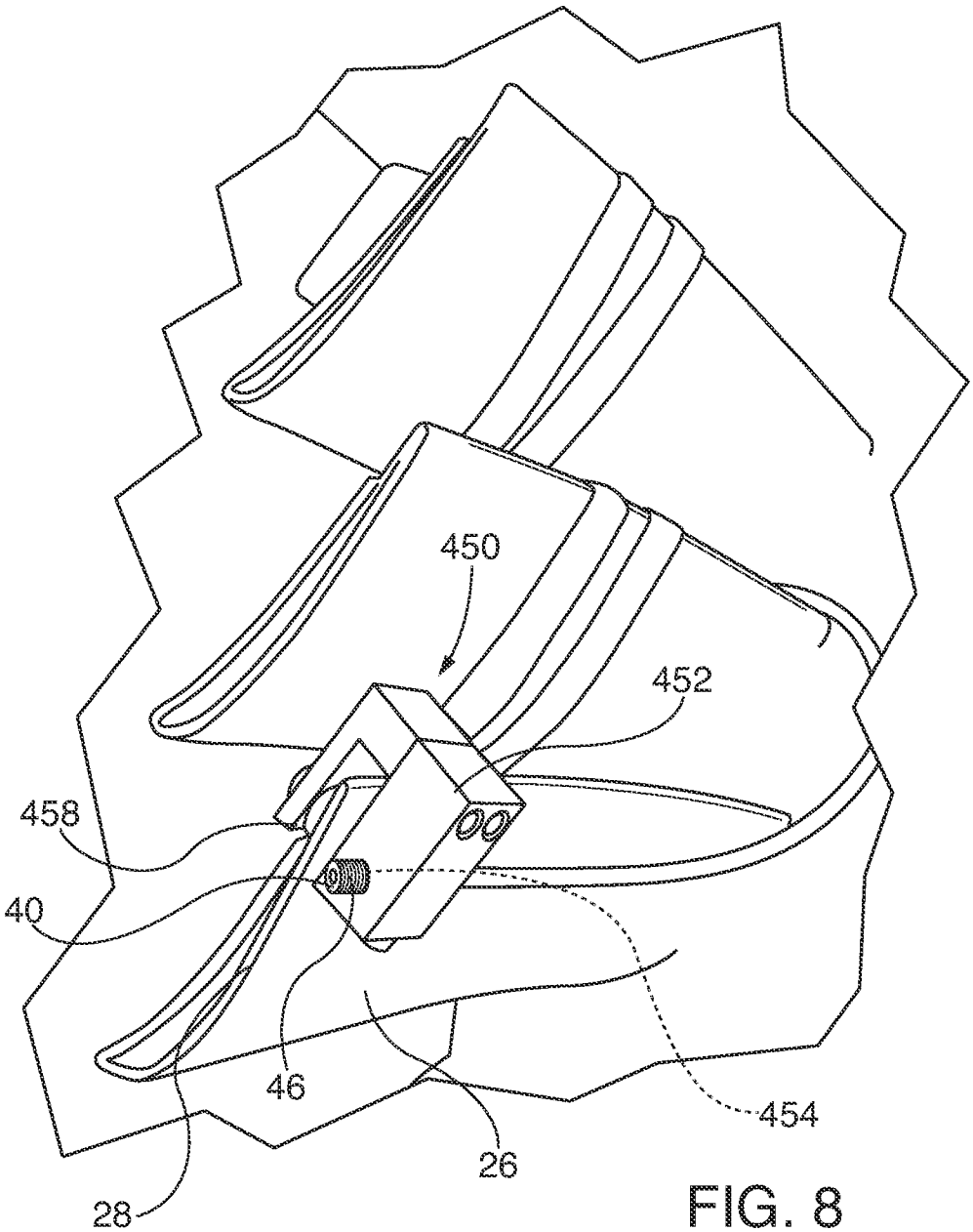


FIG. 8

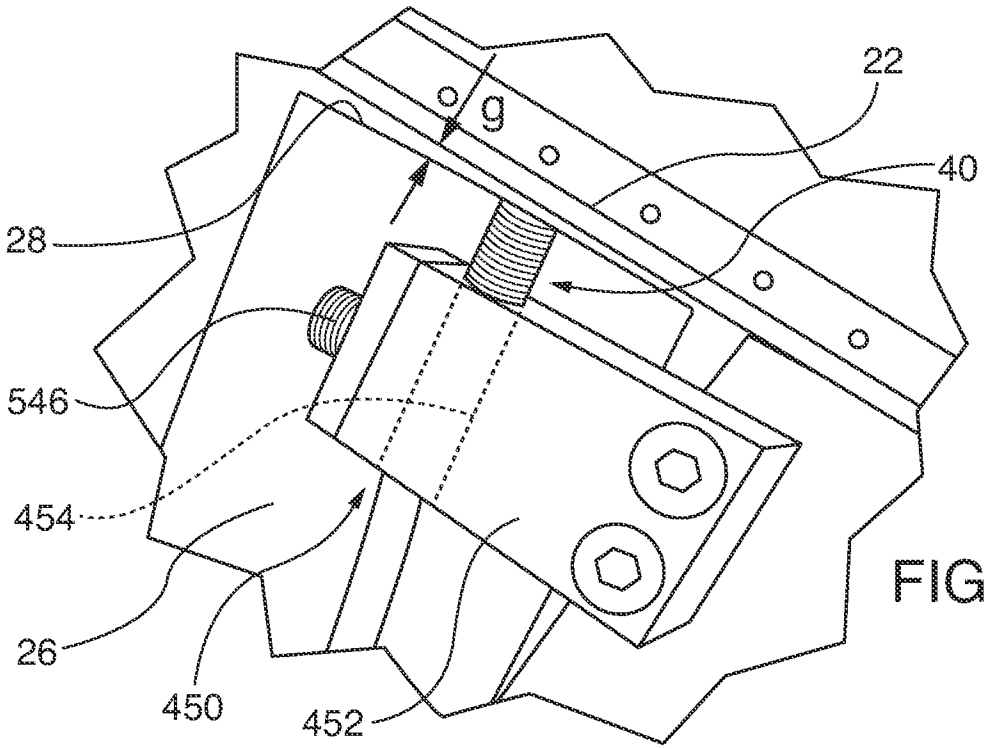


FIG. 9

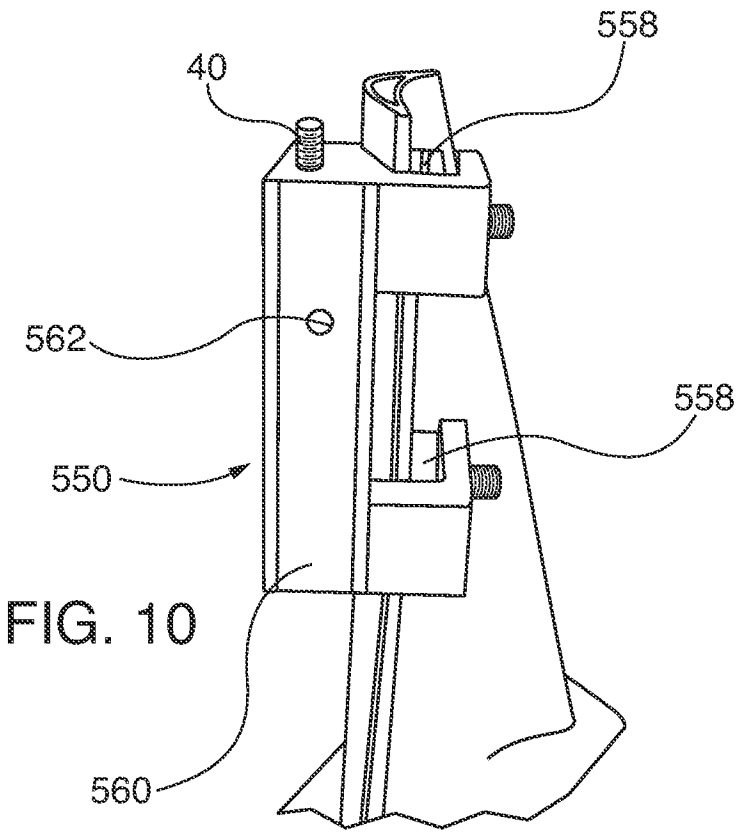


FIG. 10

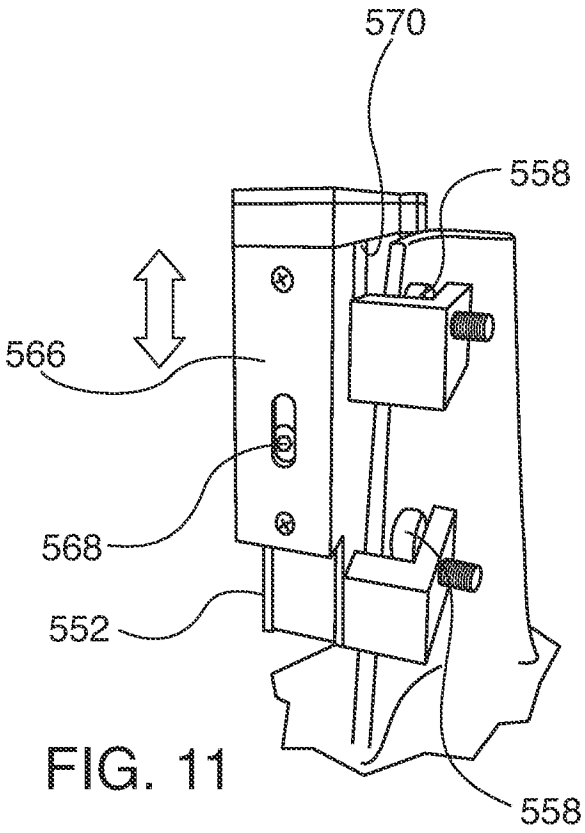


FIG. 11

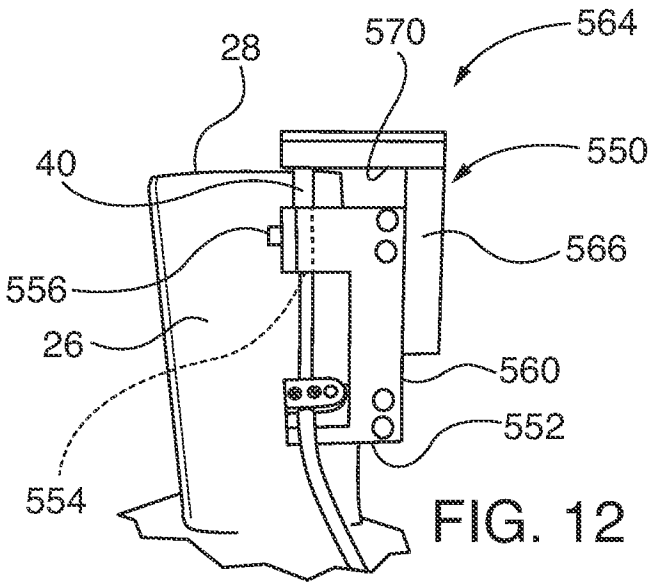


FIG. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/053635

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01B11/14 G01B5/14
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2009/289620 A1 (SUCKLING MARTIN S [GB] ET AL) 26 November 2009 (2009-11-26) paragraphs [0032], [0036], [0041], [0044]; figures 1-6	1,7 1-20
Y	US 2010/046008 A1 (GHULAM YOUNAS [GB]) 25 February 2010 (2010-02-25) paragraphs [0031], [0032], [0035]; figures 1,3,4,6	1,7
X Y	US 5 670 879 A (ZOMBO PAUL J [US] ET AL) 23 September 1997 (1997-09-23) column 3, line 27 - column 4, line 39	12,14, 18,20 1-20
X Y	US 4 322 887 A (BURTON CLARK R) 6 April 1982 (1982-04-06) column 7, line 28 - column 8, line 2; figures 1,2,4	12 1-20

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 October 2014	29/10/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Grand, Jean-Yves

2

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/053635

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 911 004 A (LEON ROBERT L [US]) 27 March 1990 (1990-03-27)	12,13,18
Y	figure 3	1-20

Y	US 4 632 352 A (STOLL KURT [DE]) 30 December 1986 (1986-12-30) the whole document	1-20

Y	US 2008/190211 A1 (SECQ JEAN [FR]) 14 August 2008 (2008-08-14) the whole document	1-20

Y	US 2013/167392 A1 (BOYER JESSE R [US] ET AL) 4 July 2013 (2013-07-04) the whole document	1-20

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2014/053635

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009289620 A1	26-11-2009	GB 2460248 A	25-11-2009
		US 2009289620 A1	26-11-2009
US 2010046008 A1	25-02-2010	GB 2462829 A	24-02-2010
		US 2010046008 A1	25-02-2010
US 5670879 A	23-09-1997	NONE	
US 4322887 A	06-04-1982	NONE	
US 4911004 A	27-03-1990	CA 1337581 C	21-11-1995
		DE 68906333 D1	09-06-1993
		DE 68906333 T2	09-12-1993
		EP 0357966 A1	14-03-1990
		ES 2064396 T3	01-02-1995
		JP 2716809 B2	18-02-1998
		JP H02162221 A	21-06-1990
		US 4911004 A	27-03-1990
US 4632352 A	30-12-1986	DE 3344010 C1	20-06-1985
		FR 2556090 A1	07-06-1985
		GB 2152999 A	14-08-1985
		IT 1177341 B	26-08-1987
		JP H0261087 B2	19-12-1990
		JP S60157328 A	17-08-1985
		US 4632352 A	30-12-1986
US 2008190211 A1	14-08-2008	AT 518126 T	15-08-2011
		CA 2608980 A1	30-11-2006
		CN 101180529 A	14-05-2008
		EP 1883800 A1	06-02-2008
		FR 2886402 A1	01-12-2006
		JP 5080455 B2	21-11-2012
		JP 2008542700 A	27-11-2008
		US 2008190211 A1	14-08-2008
		WO 2006125904 A1	30-11-2006
US 2013167392 A1	04-07-2013	EP 2610578 A2	03-07-2013
		US 2013167392 A1	04-07-2013