The present invention comprises a wide angle lens optical viewing system for the non-destructive monitoring of a high temperature area of interest with a confined space access, in particular, in a gas turbine engine. A novel cooling scheme is claimed that functions to cool the wide angle lens. Further, a method of monitoring an annular combustor region in the gas turbine via the optical viewing system is presented.
OPTICAL VIEWING SYSTEM FOR MONITORING A WIDE ANGLE AREA OF INTEREST EXPOSED TO HIGH TEMPERATURE

FIELD OF THE INVENTION

[0001] The present invention relates generally to optical based monitoring systems and, more particularly, to optical based monitoring systems for monitoring a high temperature, wide angle area of interest such as an annular combustion chamber.

BACKGROUND OF THE INVENTION

[0002] Gas turbine engines are known to include a compressor section, a combustor section, and a turbine section. Many components that form the turbine section, such as the stationary vanes, rotating blades and surrounding ring segments, are directly exposed to hot combustion gasses that can exceed 1500 °C and travel at rotational velocities approaching the speed of sound.

[0003] In some gas turbine engines, the combustion section is a 360° plenum, more commonly referred to as an annular combustor. Annular combustors typically have ceramic tiles arranged on the inner wall of the annular combustor to insulate the combustor cylinder from the hot, combusted gas.

[0004] However, these ceramic tiles have been known to detach from the inner wall and can enter the flow stream, become lodged in the first row vanes, resulting in local flow blockage. This flow blockage may result in significant damage to turbine components downstream of the first row vanes.

[0005] In the past, inspection for damage to turbine components has been performed by partially disassembling the gas turbine engine and performing visual inspections on individual components. Alternatively, in-situ visual inspections may be performed without engine disassembly by using a borescope inserted into a gas turbine engine, but such procedures are labor intensive, time consuming, costly, and require that the gas turbine engine be shut down.

[0006] It is known to inspect for turbine component damage while the gas turbine is operating. Also, several methods and apparatus for detecting and locating defects in turbine components while the turbine engine is in operation have been proposed, including acoustic, optical and infrared. However, each of these methods and apparatus has appreciable disadvantages.

[0007] Accordingly, there continues to be a need for improved methods and apparatus having a wide angle field of view for the non-destructive detection of damage to turbine components.

SUMMARY OF THE INVENTION

[0008] The present invention provides an optical viewing system for the non-destructive monitoring of a high temperature area of interest within a confined space, comprising an IR imaging device; an optical probe, having a shaft, a wide angle IR objective lens, and a relay optics unit; a cooling system adapted to cool the wide angle IR objective lens; and a processor that converts a detected image to a digital signal and display the digital signal on a visual monitor.

[0009] The present invention also provides an optical probe for monitoring an annular combustion chamber within the turbine, comprising: a shaft having a first end and a second end; a wide angle IR objective lens arranged towards the first end of the shaft; and a cooling hole arranged towards the first end of the shaft and adjacent to the wide angle IR objective lens to provide cooling air to the wide angle IR objective lens.

[0010] Furthermore, the present invention provides a method for monitoring an annular combustion chamber in an operating turbine generator, comprising attaching an appropriate wide angle IR lens to a probe tip of an optical probe; installing the optical probe in the annular combustion chamber; operating the turbine; focusing a lens in the optical probe; capturing an image with an IR camera; and processing the captured image.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The above-mentioned and other concepts of the present invention will now be described with reference to the drawings of the exemplary and preferred embodiments of the present invention. The illustrated embodiments are intended to illustrate, but not to limit the invention. The drawings contain the following figures, in which like numbers refer to like parts throughout the description and drawings and wherein:

[0012] FIG. 1 is a cross section view of a combustion section of an exemplary gas turbine fitted with an optical viewing system of the present invention.

[0013] FIG. 2 is a perspective view of an optical probe of the viewing system of the present invention.

[0014] FIG. 3 is a detail view of a lens portion of the optical probe, and

[0015] FIG. 4 is a detail view of an alternate cooling scheme for the optical probe.

DETAILED DESCRIPTION OF THE INVENTION

Overview

[0016] The invention described herein employs several basic concepts. For example, one concept relates a wide angle viewing system that is cooled by active cooling for use in a high temperature environment. Another concept relates a device and a method for monitoring ceramic tile integrity on the inner wall of an annular combustion chamber. Another concept relates to the monitoring of an area of interest where wide-angle viewing of a high temperature region through a confined access space is needed.

[0017] It is advantageous to define the term “area of interest” before describing the invention. “Area of interest” refers to any region where viewing or monitoring is desired. For example, the interface between the row 1 vane and the combustion chamber in an annular combustor in a gas turbine would be an area of interest.

[0018] The present invention is disclosed in context of use of a wide-angle infrared (IR) optical viewing system within a gas turbine engine for monitoring thermal insulating tile fixity on the combustion chamber inner wall within an annular combustion chamber. The principles of the present
invention, however, are not limited to use within gas turbine engines or to monitor thermal insulating tiles in an annular combustion chamber. Other applications include any environment requiring monitoring by viewing a wide area such as in steam turbines, electric generators, air or gas compressors, auxiliary power plants, and the like. Additionally, other types of high temperature conditions that can be monitored in the context of use within a combustion turbine with the present invention include cracked or broken components as well as combustion flame characteristics. One skilled in the art may find additional applications for the apparatus, processes, systems, components, configurations, methods and applications disclosed herein. For example, the claimed invention has application in the field of geology monitoring rocks exposed to high temperatures in the earth’s subsurface. Further, the claimed invention also has application in the field of fire rescue where monitoring by viewing a confined space in a burning, or recently burned structure is necessary. Thus, the illustration and description of the present invention in context of an exemplary gas turbine engine for monitoring stability and fixity of ceramic thermal insulation tiles on the inner wall of an annular combustion chamber is merely one possible application of the present invention. However, the present invention has particular applicability for use as a viewing system for monitoring the condition of turbine components.

Components

[0019] Referring to FIG. 1, the preferred embodiment of the claimed invention is illustrated and disclosed in the context of a wide angle viewing system 10 adapted to monitor the condition of the thermal insulating tiles 20 lining the inner cylinder wall 25 of the combustion cylinder 22 in an operating gas turbine. The viewing system 10 advantageously comprises an objective lens 36 (see FIG. 2) having a wide angle field of vision 18 allowing a portion of the area of interest, or the entire area of interest to be viewed. The image is transferred through an optical probe 28 to an IR imaging device 26 that is attached toward an end of the optical probe 28. The image detected by the IR imaging device 26 is converted to a digital signal and transmitted to a processing system 48. The processed image can then be viewed on a monitor using conventional image rendering program applications or stored.

[0020] Still referring to FIG. 1, the IR imaging device 26 is preferably an IR camera 26. The IR camera 26 preferably uses a focal plane array sensor (e.g., an array of charged coupled devices) to measure the emitted radiance of the entire area of the surface to be measured. One suitable IR camera 26 is described in pending U.S. patent application Ser. No. 09/470,123 which is incorporated herein by reference in its entirety. Although the IR camera 26 disclosed in Ser. No. 09/470,123 is specifically adapted to capture a dynamic event having a short integration time (e.g., motion requiring an ultra fast aperture speed of a few microseconds), such a short integration time is not required for the present invention because the event to be visually monitored is a static event (e.g., detached thermal insulating tiles 22 lodged in the flow inlet region 17 of the row 1 vanes 16). However, although an IR camera 26 having a short integration time is not required for monitoring a static event, it may be beneficial to use an IR camera having a short integration time to capture dynamic events in other contexts of use. Furthermore, if the engine components are hot enough to emit light (i.e., glow), non IR camera 26 operating in the visible light spectrum may be used. If an IR camera 26 is used, it 26 preferably operates with a wavelength ranging from 0.9 μm to 12 μm.

[0021] Further illustrated in FIG. 1 is a processing element 48. The processing element 48 allows for the user to view the detected image. In the preferred embodiment, the IR camera 26 is operatively connected to the processing element 48 by a cable connection 50 or other suitable connection such as telemetry or a wireless area network. The processing element 48 further comprises a video monitor that allows the user monitor by viewing the area of interest 17. The processing element 48 may further enhance the viewed image via image processing software and then display the processed image on the video monitor.

[0022] Referring to FIG. 2, the illustrated optical probe 28 is exemplarily arranged prior to the row 1 vane 16 and the inner surface 25 of the combustion chamber 30 (see FIG. 1). The optical probe 28 is advantageously comprised of a shaft 32, a wide angle lens 36, and a relay optics unit 34. The shaft 32 has a length sufficient to traverse the cylinder wall 22 from the outer surface 23 of the combustor cylinder 22 to the inner surface 25 of the combustor cylinder 22 and through the thermal insulating tiles 20 to view the area of interest 17 (see FIG. 1). Although there is no requirement that the optical probe 28 be located in the combustion chamber 30 as illustrated, it 28 is preferably arranged such that the field of vision 18 can detect the area of interest 17. The shaft 32 may be circular in cross section. Shafts 32 having circular cross sections are low in cost and readily commercially available. Furthermore, the shaft 32 having a circular cross section may be inserted into a circular hole in the cylinder wall 22. However, a shaft having any cross sectional geometry such as triangular or rectangular cross sections may be used. Additionally, combinations of different shafts 32 cross sections may be connected to produce a single shaft 32 having different cross sections. The shaft 32 will have sufficient wall thickness to withstand the extreme temperatures and pressures of the environment. Additionally, the shaft 32 should have an inner wall diameter sufficient to provide the image to the IR camera. The shaft 32 is preferably metallic in composition and more preferably is a stainless steel to provide material properties sufficient to properly function in a high temperature environment. Stainless steel shafts 32 are preferred because they are cost effective and readily commercially available. The shaft 32 may be coated with a thermal insulating such as a ceramic coating material to improve the temperature resistance of the shaft 32.

[0023] One or more cooling ports 40 are advantageously arranged on the shaft 32 at a location that allows cooling air to enter the shaft 32. The cooling air functions to keep the optical elements 36, 34 properly cooled. Cooling air can be supplied as bleed air extracted from a compressor section or may be supplied from any suitable location where cooling air can be obtained.

[0024] Still referring to FIG. 2, the optical probe 28 is further comprised of a relay optics unit 34 having one or more lens that is arranged internal to the shaft 32. The relay optics unit 34 aids in transferring and focusing the image detected in the combustion chamber 30 through the shaft 32 to the IR camera 26. As illustrated, the optical probe 28 contains a single relay optics unit 34. However, multiple relay optic units 34 may be installed as required.
A wide angle IR objective lens 36 is located toward an end of the shaft 32 opposite the end that the IR camera 26 is located. The wide angle lens 36 allows a wide area of interest 17 to be viewed. The wide angle lens 36 is advantageously designed with a wide field of vision 18 or wide viewing angle 18. Typically, a wide field of vision 18 or wide viewing angle 18 is preferably larger than 30 degrees. However, the field of vision 18 may be less than 30 degrees. The viewing capabilities of the lens 36 are partially effected by the field of vision 18. For example, a lens 36 having a field of vision 18 greater than 150 degrees will not have the imaging capabilities of a lens 36 having a field of vision 18 less than 90 degrees. With a larger field of vision 18 is a tradeoff in perspective, detail, and resolution.

As illustrated, the field of vision 18 is depicted as an angle. In three dimensional space, the field of vision 18 can be thought of as generally conical in shape with the apex of the cone at the lens 36. The wide angle lens 36 is preferable hemispherical in shape. A hemispherical lens 36 provides a wide field of vision 18 and is commercially readily available. However, there is no requirement that the lens 36 be hemispherical and there may be acceptable alternate geometries such as an ellipsoid, a hyperboloid, and the like. As illustrated, the lens 36 is approximately 17 millimeters in diameter. While the illustrated embodiment of the lens 36 diameter is approximately 17 millimeters, one skilled in the art will recognize that the diameter of the lens 36 will in part depend on the amount of available energy emitted by the area of interest 17. Furthermore, there are other considerations that may be used in determining lens 36 size such as the size of the entry port for the optical probe shaft 32 and cooling flow availability.

The lens 36 may be interchangeable with the optical probe 28. That is, depending on the application, it may be beneficial to use a lens 36 having a more narrow field of vision 18. For example, if the area of interest 17 to be monitored can be acceptably monitored with a lens having a more narrow (e.g., less than 180 degrees) field of vision 18, then there is no limitation preventing use of the lens 36. As discussed below, there are advantages to using a lens 36 having a field of vision 18 no greater than required for the particular context of use.

In the preferred embodiment, the IR objective lens 36 is a germanium lens 36. A germanium lens 36 is transmissive in the wavelength range of 0.9 μM to 12 μM. Other materials are suitable, such as barium fluoride, zine selenide, and the like. However, as would be known by one skilled in the art, the IR objective lens 36 can be produced from any acceptable material. The material may also be coated 46 (see FIG. 3) to further protect the lens 36. The coating material 46 will typically have the same wavelength as the IR camera 26. The lens 36 may protrude into the combustion chamber 30 provided adequate cooling can be achieved to properly cool the lens 36.

The lens 36 must be properly cooled. If the lens 36 becomes heated to the level that it 36 begins to become emissive, the area of interest 17 will be unobservable.

A cooling scheme 42 for the IR objective lens 36 is illustrated in FIG. 3. The cooling 52 air functions to keep the temperature of the lens 36 during operation below a light emitting level. As cooling air 52 preferably enters the shuff through the cooling ports 40 and flows through the shuff exiting through cooling holes 42. As illustrated, a plurality of evenly spaced circular cooling holes 42 is located toward the circumference or periphery of the IR objective lens 36. There is no requirement that the cooling holes be evenly spaced or located toward the circumference or periphery of the lens 36. The lens 36 may be surrounded by a sufficient number of cooling holes 42 to provide adequate cooling to the lens 36 and need not be located on the circumference of the lens 36. A single cooling hole 42 may be a sufficient number of cooling holes 42 to properly cool the lens 36. If desired, more cooling holes 42 than necessary to adequately cool the lens 36 may be used. Furthermore, there is no requirement that the cooling hole be circular in shape. For example, the cooling hole 42 types that may be used include a shaped cooling hole 42, a fan shaped cooling hole 42, or a cooling hole 42 with a diffuser. Cooling hole 42 shapes as just mentioned may provide a more efficient cooling of the lens 36. Other cooling hole 42 geometries such as a slot, a rectangle, an ellipse, and the like may be used to meet the cooling requirements of the lens 36. Selection of cooling hole 42 shape or geometry may be effected by cooling requirements and manufacturing costs with the circular cooling hole 42 being the least expensive to manufacture. Additionally, any combination of the mentioned geometries or hole shapes may be used to adequately cool the lens 36.

The cooling flow 52 may be directed the lens 36 as necessary to cool the lens 36. By way of example, the cooling flow 52 may be angled from the cooling hole 42 towards the lens 36.

As illustrated, the lens 36 is cooled by film cooling. As known by those skilled in the art, film cooling is a proven method of cooling components. That is, a thin film of air is developed between the combustion gas and the lens 36 effectively insulating the lens 36 from the gas. The thickness and flow rate of the film is controlled by the cooling hole 42 geometry. The cooling flow may be in the turbulent flow regime or laminar flow regime. The insulating effect of the film cooling may provide a temperature difference of as much as 150 C. between the combustion gas and the lens 36.

An alternate cooling scheme is illustrated in FIG. 4. Cooling holes 42 are arranged in pairs 54, 56 such that the pairs 54, 56 extend radially from the center of the optical probe 32. The hole size of each hole may be different. A benefit derived from such a scheme is the improved cooling of the lens 36. The cooling flow and direction of the inner cooling holes 54 and the outer cooling holes 56 may be advantageously adjusted to more effectively cool the lens. The velocity of the cooling flow of the inner cooling holes 54 is preferably greater than that of the velocity of the cooling flow of the outer cooling holes 56. This configuration provides a pressure differential may result directing the cooling flow of the outer cooling holes 56 closer to the lens 36. However, there is no requirement that the flow velocity of the inner hole 54 be greater than the cooling flow velocity of the outer hole 56. The pairs of cooling holes 54, 56 may be located equidistance from each other circumferentially with respect to the optical probe 32 and lens 36. It is not required that the cooling holes 54, 56 be located equidistance from each other. Furthermore, more than two cooling holes 54, 56 arranged radial with respect to the optical probe 32 may be used. Combinations of the different cooling hole arrangements may be used as well. For example, a cooling hole arrangement having pairs of cooling holes 54, 56 may be used with a plurality of single cooling holes 42.
Returning to FIG. 2, the illustrated embodiment may include a flange 38 located on the shaft 32. The flange 38 functions to attach the optical system to the combustion cylinder wall 22 and provide a seal between the combustion chamber 30 and exterior to the combustion cylinder wall 22. The flange 38 also contains a window 44 that permits the transmitted image to travel from the combustion chamber 30 to the IR camera 26.

Method of Assembly

Referring back to FIG. 1, components of the wide angle viewing system 10 may be mounted or installed within the combustor cylinder wall 22 of the gas turbine. However, other locations are suitable, for example, stationary components such as ring segments or stationary vanes 8 that permit wide angle viewing of turbine components. If portions of the wide angle viewing system 10 are located in a harsh environment (i.e., inside the combustion chamber 30), a protective casing, covering or coating advantageously is used to protect the exposed components from the aggressive combustion chamber 30 environment, as will be understood by those skilled in the art.

The illustrated optical probe 28 is inserted through a port in the combustor cylinder wall 22 and traversed through the port into the combustion chamber 30. The optical probe 28 can be arranged in many other locations to achieve the function of wide angle viewing as will be understood by those skilled in the art. The field of vision 18 into the plane can be increased by increasing the number of optical viewing systems 10 used. For example, by spacing an appropriate number of optical viewing systems 10 around the circumference of the annular combustion chamber 30, the entire combustion chamber 30 may be viewed.

The optical probe 28 is advantageously secured to the combustor cylinder wall 22 by an optional flange 38. In the context of use in a gas turbine, the cylinder wall 22 is a convenient location to secure the optical probe 28 to view the area of interest 17. The flange 38 also provides a seal between the combustion chamber 30 conditions external to the combustor cylinder wall 22. One skilled in the art will recognize that there are other options available to secure the optical probe 28 in an operating position. For example, the optical probe 28 may be welded in place, adhesively fixed in place, screwed in place with a threaded shaft 32, magnetically fixed in place, secured using thumb screws, combinations thereof, and the like. Furthermore, the optical probe 28 may be adjustably mounted such that the probe 28 can be extended to possibly increase the field of view 18, or retracted to decrease the field of view 17 or adjust the lens 36 cooling if necessary.

Method of Operation

In operation, as illustrated, when the viewing system 10 is initiated, the IR camera 26 detects the image captured through the wide angle lens 36. The image is converted to a digital signal and transmitted to the processing system 48.

The viewing system 48 advantageously interprets and processes the transmitted image. The processed image is preferably output in a form that can be suitably visually displayed. For example, a visual output, such as a computer monitor advantageously allows the data to be displayed in a real time fashion because of the capabilities of modern central processing units. Alternatively, the data could be stored separately and used with a suitable program or database and analyzed at a later date. Lastly, the output could be used and compared to other output to determine trends in the systems being monitored.

While the preferred embodiments of the present invention have been shown and described herein, it will be obvious that such embodiments are provided by way of example only. Numerous variations, changes and substitutions will occur to those of skill in the art without departing from the invention herein. Also, one or more aspects or features of one or more embodiments or examples of the present invention may be used or combined with one or more other embodiments or examples of the present invention. Accordingly, it is intended that the invention be limited only by the spirit and scope of the appended claims.

We claim as our invention:

1. An optical viewing system for the non-destructive monitoring of a high temperature area of interest with a confined space access, comprising:

   an IR imaging device;

   an optical probe, having a shaft, a wide angle IR objective lens, and a relay optics unit;

   a cooling system adapted to cool the wide angle IR objective lens; and

   a processor that converts a detected image to a digital signal and display the digital signal on a visual monitor.

2. The viewing system as claimed in claim 1, wherein the high temperature, closed area of interest is a combustion chamber.

3. The viewing system as claimed in claim 2, wherein a plurality of viewing systems are used to view a plurality of combustion chambers, the plurality of combustion chambers arranged annularly on a combustion turbine.

4. The viewing system as claimed in claim 1, wherein the optical probe is located in a port in a turbine having a cylinder.

5. The viewing system as claimed in claim 1, wherein the wide angle IR objective lens is cooled.

6. The viewing system as claimed in claim 1, wherein the wide angle IR objective lens is cooled with cooling flow from a compressor connected to the turbine.

7. The viewing system as claimed in claim 1, further comprising a plurality of relay optical units arranged within the optical probe.

8. The viewing system as claimed in claim 1, wherein the IR viewing device is an IR camera.

9. The viewing system as claimed in claim 1, wherein the integration time is greater than 3 micro-seconds.

10. The viewing system as claimed in claim 8, wherein the IR camera operates with a frequency in the range of 0.9 μm to 12 μm.

11. The viewing system as claimed in claim 1, wherein the wide angle IR objective lens is made of germanium.

12. The viewing system as claimed in claim 1, wherein the wide angle IR objective lens is made from a material selected from the group consisting of germanium, barium fluoride, zinc selenide, and the like.
13. The viewing system as claimed in claim 2, wherein the wide angle IR objective lens is coated with a material having a frequency that matches the operating frequency of the IR camera.

14. An optical probe for monitoring an annular combustion chamber within the turbine, comprising:
   a shaft having a first end and a second end;
   a wide angle IR objective lens arranged towards the first end of the shaft; and
   a cooling hole arranged toward the first end of the shaft and adjacent to the wide angle IR objective lens to provide cooling air to the wide angle IR objective lens.

15. The probe as claimed in claim 14, further comprising a relay optics unit.

16. The probe as claimed in claim 14, wherein the shaft is made of stainless steel.

17. The probe as claimed in claim 14, wherein the shaft has a cooling port for cooling air to enter.

18. The probe as claimed in claim 14, wherein the shaft is adapted to allow cooling air to enter through a plurality of cooling ports.

19. The probe as claimed in claim 14, wherein a plurality of cooling holes provide cooling air to the wide angle IR objective lens.

20. The probe as claimed in claim 19, wherein the cooling holes are evenly spaced relative to the wide angle IR objective lens.

21. The probe as claimed in claim 19, wherein the cooling hole geometry is selected from the set of cooling hole geometries consisting of a shaped hole, a fan shaped hole, a hole with a diffuser, a slot, a rectangle, an ellipse, and the like, and combinations thereof.

22. The probe as claimed in claim 19, wherein the cooling holes are located peripherally to the wide angle IR objective lens.

23. The probe as claimed in claim 19, wherein pairs of cooling holes are arranged peripherally to the wide angle IR objective lens and extend radially from the center of the optical probe.

24. The probe as claimed in claim 19, wherein more than two cooling holes are arranged peripherally to the wide angle IR objective lens and extend radially from the center of the optical probe.

25. A method for monitoring an annular combustion chamber in an operating turbine generator, comprising:
   attaching an appropriate wide angle IR lens to a probe tip of an optical probe;
   installing the optical probe in the annular combustion chamber;
   operating the turbine;
   focusing a lens in the optical probe;
   capturing an image with an IR camera; and
   processing the captured image.

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