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(54) OPTICAL VIEWING SYSTEM FOR MONITORING A WIDE ANGLE AREA OF INTEREST EXPOSED TO HIGH TEMPERATURE

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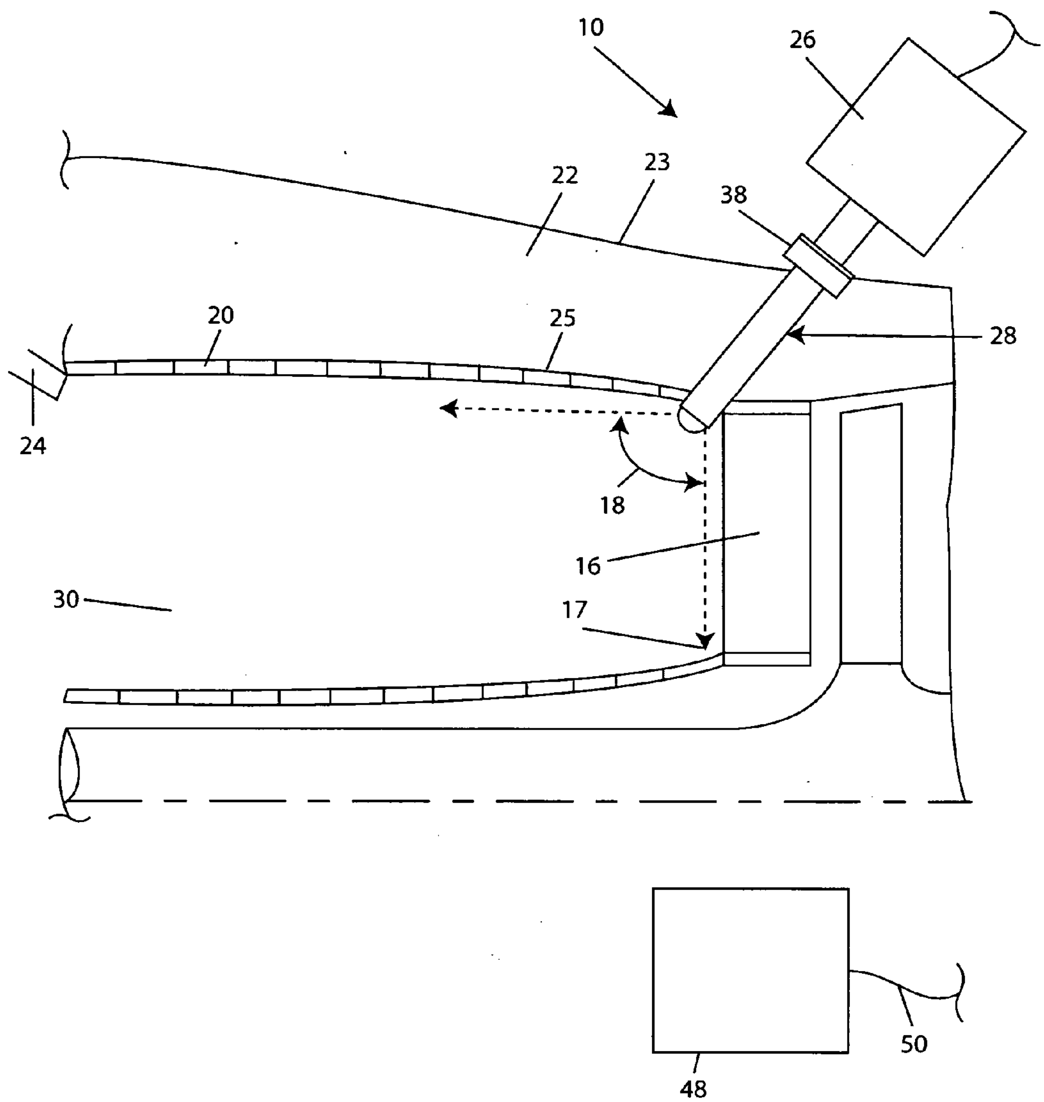
(57) **ABSTRACT**

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.



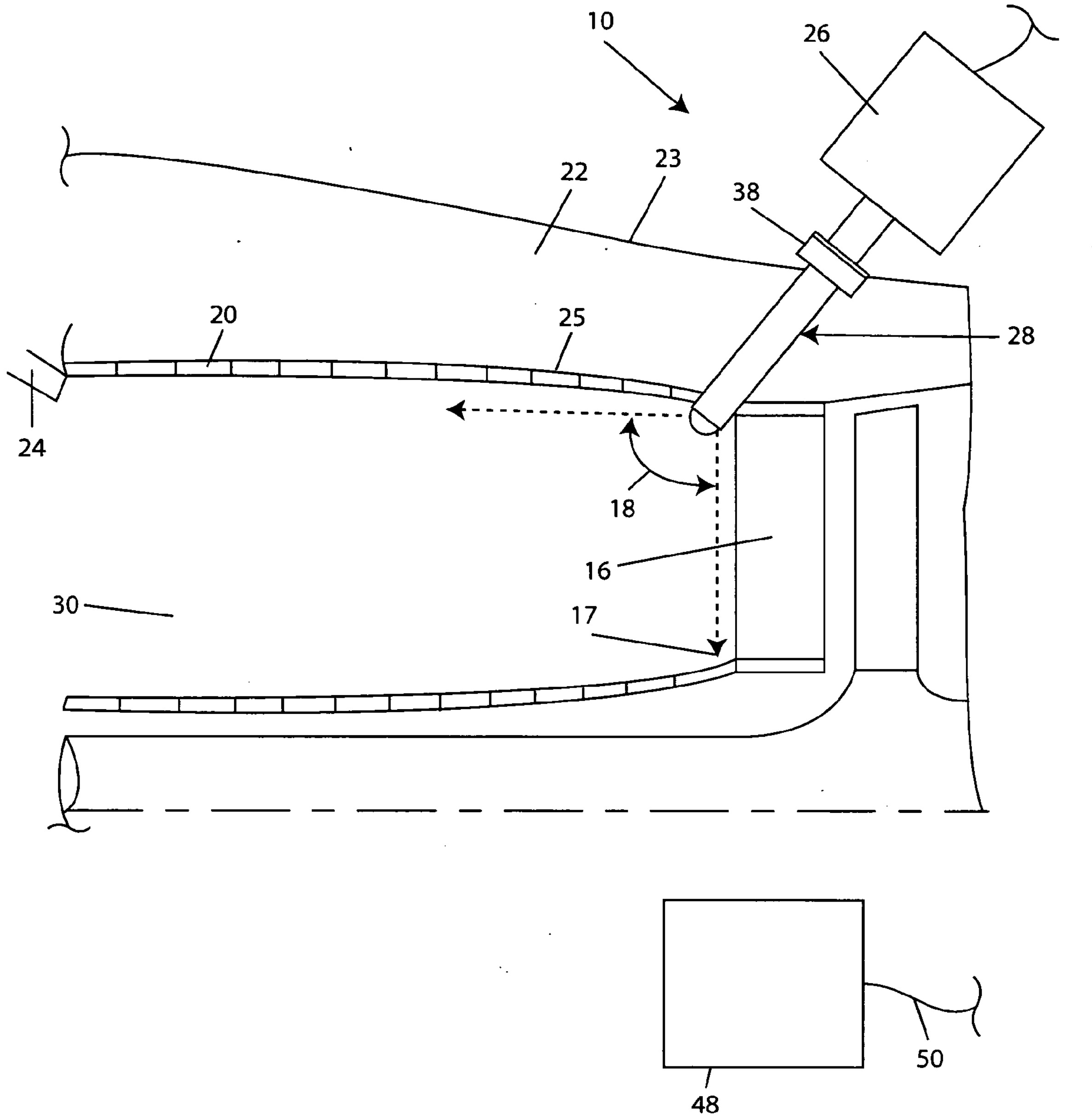


Figure 1

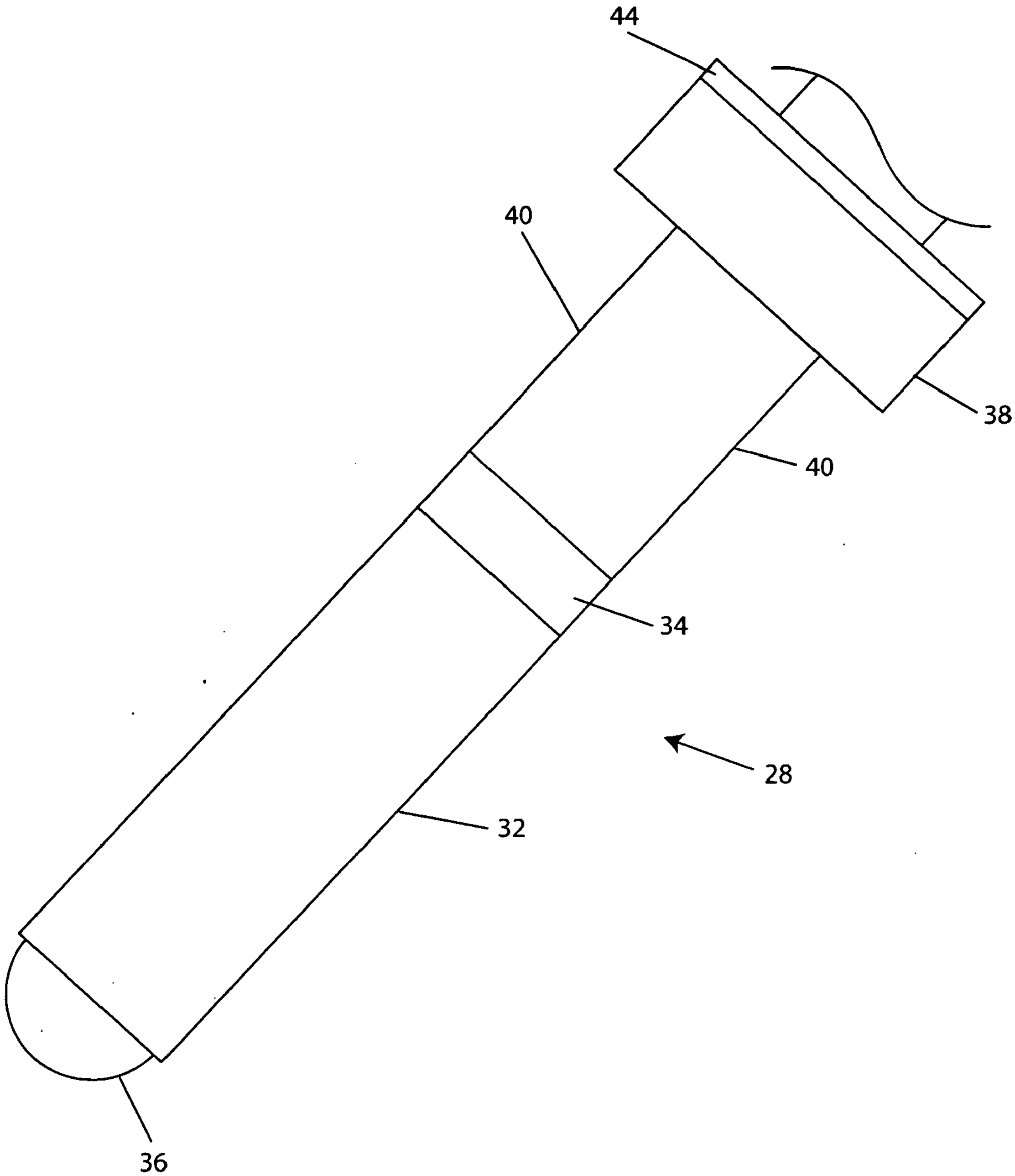


Figure 2

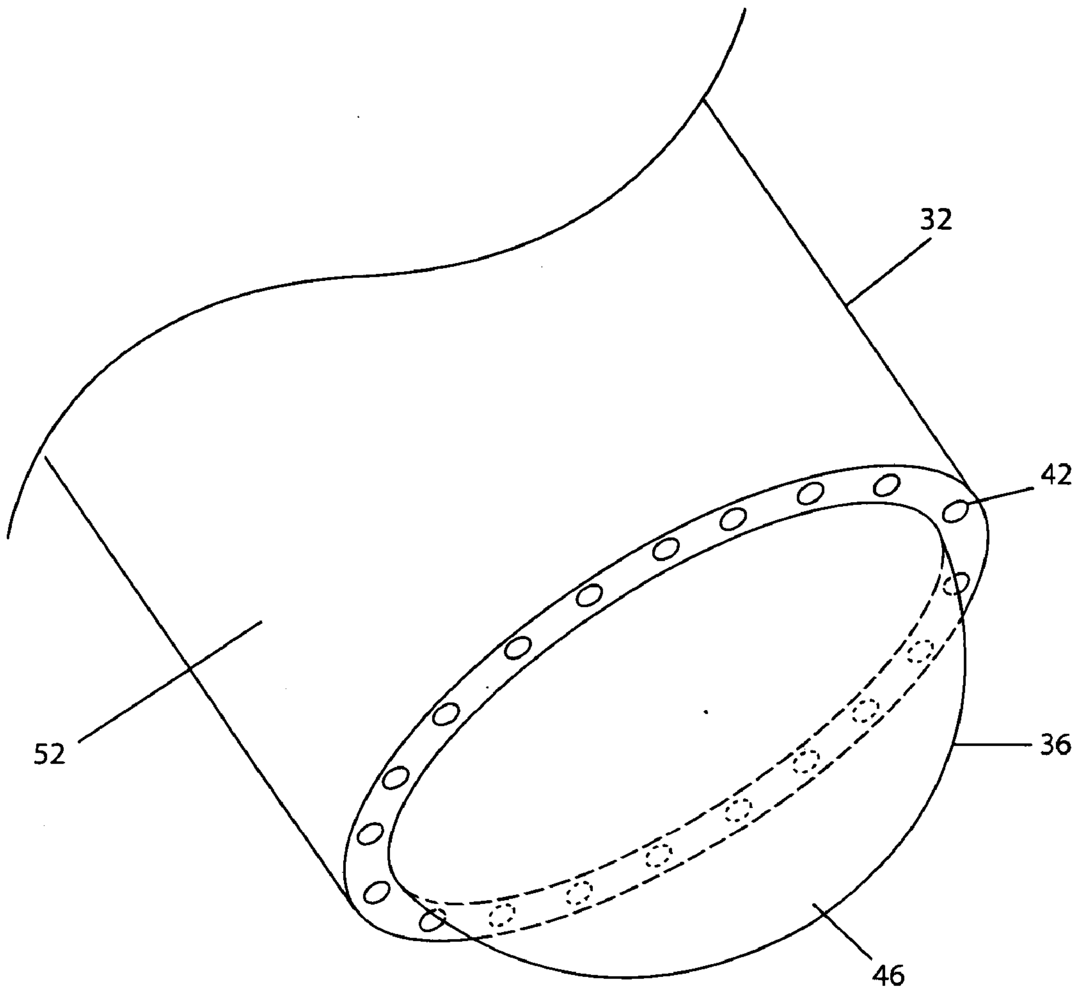


Figure 3

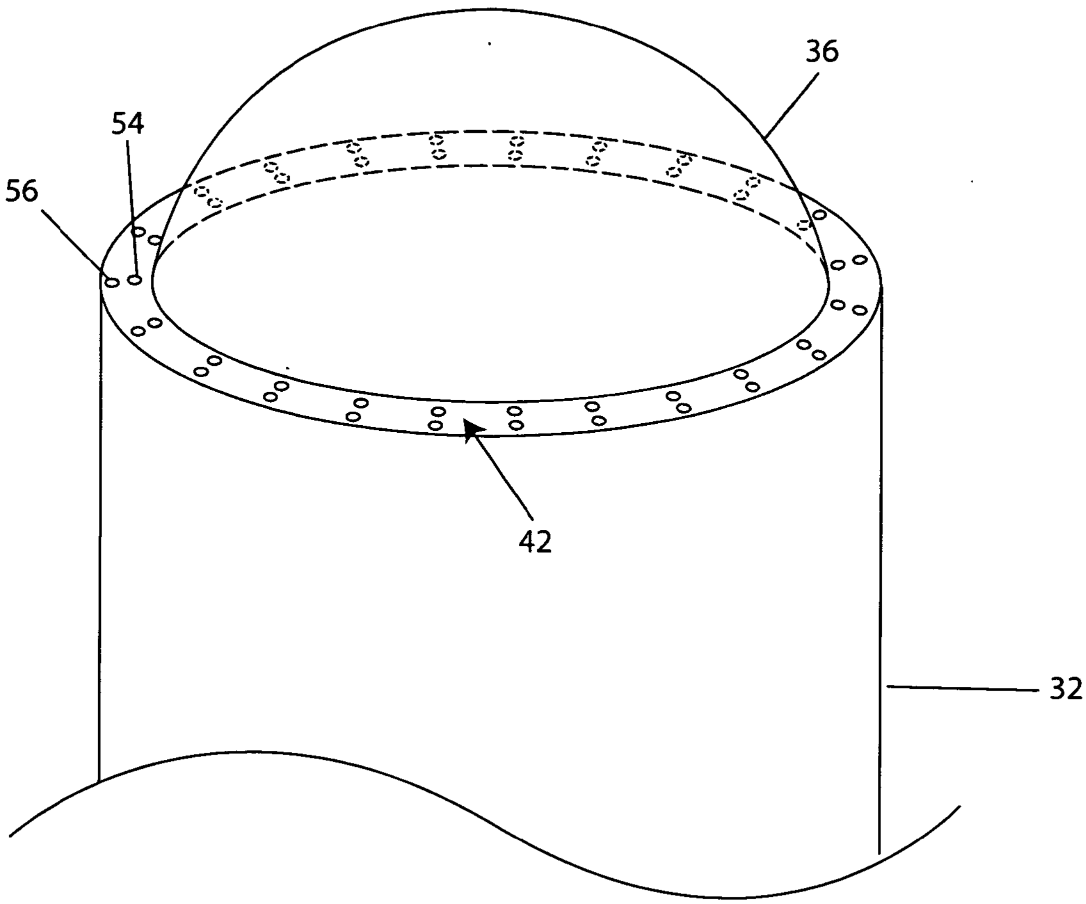


Figure 4

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 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.

[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 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.

[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 pockets 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 preferrably 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 shaft **32** cross sections may 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.

[0025] 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.

[0026] 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.

[0027] 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.

[0028] 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, zinc selinide, 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**.

[0029] 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.

[0030] 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 shaft through the cooling ports **40** and flows through the shaft 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**.

[0031] 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**.

[0032] 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 de rived 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**.

[0033] Returning to **FIG. 2**, the illustrated embodiment may includes 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

[0034] 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.

[0035] 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.

[0036] 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

[0037] 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**.

[0038] 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.

[0039] 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 selinide, 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.

* * * * *