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1 Attorney Docket No. 79478

2
3 SYSTEM AND METHOD FOR DETERMINING THE TEMPERATURE
4 TO WHICH A STRUCTURE IS SUBJECTED
5

6 STATEMENT OF GOVERNMENT INTEREST

7 The invention described herein may be manufactured and used by
8 or for the Government of the United States of America for
9 governmental purposes without the payment of any royalties
10 thereon or therefor.
11

12 CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

13 Not applicable.
14

15 BACKGROUND OF THE INVENTION

16 (1) Field Of The Invention

17 The present invention generally relates to a system and method
18 for determining the temperature to which a structure is
19 subjected.

20 (2) Description of the Prior Art

21 The temperature of a fluid surrounding an elongated probe
22 provides important diagnostic information for structures within
23 the fluid, e.g., in the medical field. There have been several

1 conventional techniques for measuring such temperature, such as
2 embedding thermister-type sensors in the probe wherein each
3 thermister-type sensor is supported by a pair of wires. Another
4 conventional technique utilizes fiber optic sensors based upon
5 Bragg gratings. Bragg gratings are described in U.S. Patent Nos.
6 5,493,390, 5,563,967, and 5,892,860. Bragg grating-type sensors
7 have advantages over thermister-type sensors because fiber-optic
8 sensors can exist on one fiber. Fiber optic sensors based on
9 Bragg gratings sense temperature based on strain on the sensor.
10 However, such strain also can be induced by non-temperature
11 effects such as hydrostatic pressure, tension, bending, etc.
12 which can cause erroneous temperature measurements. Another
13 optional method to measure temperature makes use of Raman
14 scattering effects. Here, light is scattered from the
15 inhomogeneities in the glass and the scattered light is processed
16 to determine temperature. However, it is difficult to obtain a
17 point of measurement by this method as the spatial resolution is
18 about $\frac{1}{2}$ meter.

19 Therefore, it is an object of the present invention to provide
20 a novel system and method for measuring the temperature of a
21 fluid surrounding a probe wherein such system and method do not
22 exhibit or present the problems and disadvantages of conventional
23 techniques.

1 Other objects and advantages of the present invention will be
2 apparent to one of ordinary skill in the art in light of the
3 ensuing description of the present invention.

5 SUMMARY OF THE INVENTION

6 In one aspect, the present invention is directed to a system
7 for determining the temperature to which a structure is
8 subjected, comprising an optical fiber configured for attachment
9 to a structure, a pair of fiber sensors formed within the optical
10 fiber, each fiber sensor being configured to have a particular
11 coefficient of thermal expansion and particular identification, a
12 light source for launching a broadband source of light into the
13 optical fiber, a detector for detecting the light returning from
14 the first and second fiber sensors, and a processor for
15 determining the temperature to which the structure is subjected
16 based upon the difference in the strain response of each fiber
17 sensor due to the effects of temperature upon the fiber sensors.

18 In a related aspect, the present invention is directed to a
19 method of determining the temperature to which a structure is
20 subjected, comprising the steps of providing an optical fiber
21 having at least one pair of fiber sensors formed therein wherein
22 the fiber sensors are substantially collocated and each fiber
23 sensor is configured to have a particular coefficient of thermal

1 expansion and a particular identification, attaching the optical
2 fiber to the structure, launching a broadband spectrum of light
3 into the optical fiber, detecting light returning from the fiber
4 sensors, and determining the temperature to which the structure
5 is subjected based on the difference in strain response of the
6 fiber sensors as a result of the effects of temperature upon the
7 fiber sensors.

8 In one embodiment, each fiber sensor is configured as a
9 Bragg grating.

10 In one embodiment, the identification of each fiber sensor
11 comprises a particular fiber sensor wavelength.

12 In one embodiment, one of the fiber sensors comprises a
13 coating of material that is configured to provide that fiber
14 sensor with a first coefficient of thermal expansion and the
15 other fiber sensor comprises a coating of material that is
16 configured to provide that fiber sensor with a second
17 coefficient of thermal expansion that is different than the first
18 coefficient of thermal expansion.

19 20 BRIEF DESCRIPTION OF THE DRAWINGS

21 The features of the invention are believed to be novel and
22 the elements characteristic of the invention are set forth with
23 particularity.

The Figure is for

1 illustration purposes only and is not drawn to scale. The
2 invention itself, however, both as to organization and method of
3 operation, may best be understood by reference to the detailed
4 description which follows taken in conjunction with the
5 accompanying drawing in which:

6 The Figure is a block diagram of the apparatus of the
7 present invention.

8 9 DESCRIPTION OF THE PREFERRED EMBODIMENT

10 In describing the preferred embodiments of the present
11 invention, reference will be made herein to the Figure in which
12 like numerals refer to like features of the invention.

13 The present invention provides a new and improved system and
14 method for accurately determining the temperature in a fluid
15 surrounding an elongated probe. However, it is to be understood
16 that the present invention can be used to determine the
17 temperature to which other structures are subjected, whether or
18 not such structures are in a fluid environment. Thus, many
19 applications are possible.

20 Referring to the Figure, there is shown a portion of
21 structure 10. In one embodiment, optical fiber 12 is attached or
22 mounted to structure 10. In another embodiment, optical fiber 12
23 is a stand-alone probe. Bragg grating sensors 14 and 15 are

1 integrated into optical fiber 12. In one embodiment, Bragg
2 grating sensors 14 and 15 are embedded with optical fiber 12 in
3 structure 10. In another embodiment, Bragg grating sensors 14
4 and 15 are bonded with optical fiber 12 to structure 10. Optical
5 fiber 12 has primary entry and exit point 18. In a preferred
6 embodiment, fiber sensors 14 and 15 are substantially collocated
7 so that all factors causing strain due to non-temperature effects
8 such as hydrostatic pressure, tension, bending, etc. have the
9 same effect on each Bragg grating sensor 14 and 15. Preferably,
10 fiber sensors 14 and 15 are in a low-tension environment, such as
11 would be expected in a medical probe.

12 The system of the present invention further includes optical
13 source 20, optical fiber coupler 22, optical detector 24,
14 processor 26 and interface 28. Optical source 20 is connected to
15 primary entry and exit point 18 of optical fiber 12 and emits
16 optical radiation in the direction indicated by arrow 30. Power
17 supply 31 supplies power for optical source 20. Optical fiber
18 coupler 22 couples reflected optical radiation, indicated by
19 arrow 32, to optical detector 24. Optical detector 24 outputs
20 electrical signal 34 that represents detected optical radiation.
21 Signal 34 is inputted into processor 26. Processor 26 can be
22 realized by a commercially available microprocessor such as the
23 type produced by Intel Inc., Motorola, Sun Microsystems, etc.

1 Processor 26 effects determination of strain upon each Bragg
2 grating sensor 14 and 15 and, as a result of such strain
3 determination, determines the temperature to which that portion
4 of structure 10 is subjected. This is further explained in the
5 ensuing description. Processor 26 is in data communication with
6 interface 28. Interface 28 is in data communication with user
7 input devices such as a computer, laptop notebook, meters,
8 digital signal analyzers, oscilloscopes, etc. (not shown).
9 Interface 28 is also in data communication with data display
10 devices such as computer screens, liquid-crystal displays, etc.
11 (not shown). Interface 28 allows a user to input into processor
12 26 specific calibration data pertaining to optical fiber 12 and
13 Bragg grating sensors 14 and 15. This calibration data is
14 explained in detail in the ensuing description.

15 In accordance with the present invention, each Bragg grating
16 sensor 14 and 15 is configured so that each sensor 14 and 15
17 reacts differently to temperature. This is accomplished by
18 configuring each Bragg grating sensor 14 and 15 to have a
19 different coefficient of thermal expansion. Optical fibers can
20 typically be fabricated having on the order of 2.5 micro-
21 strain/F° (micro-strain per degree Fahrenheit). Thus, in one
22 embodiment, fiber sensor 14 is left in its raw configuration
23 resulting from the manufacturing process of this sensor, while

1 fiber sensor 15 is coated with a material that provides that
2 fiber sensor 15 with a coefficient of thermal expansion that is
3 significantly different than the coefficient of thermal expansion
4 of fiber sensor 14. In a preferred embodiment, the difference
5 in the coefficients of thermal expansion of fiber sensors 14 and
6 15 is at least 5.0 micro-strain/F°. More preferably, the
7 difference in the coefficients of thermal expansion of sensors 14
8 and 15 is at least 10.0 micro-strain/F°. Most preferably, the
9 difference in the coefficients of thermal expansion of sensors 14
10 and 15 is greater than 10.0 micro-strain/F°.

11 In one example, fiber sensor 15 is coated with Aluminum or
12 Magnesium. Each of these materials has a coefficient of thermal
13 expansion of about 14.0 micro-strain/F°. If fiber sensor 14 is
14 not coated with any material, the difference in the coefficients
15 of thermal expansion of fiber sensors 14 and 15 is 11.5 micro-
16 strain/F°.

17 In an alternate embodiment, sensor 14 is coated with a
18 different material that provides sensor 14 with a coefficient of
19 thermal expansion that is significantly different than the
20 coefficient of thermal expansion of sensor 15. Thus, for
21 example, sensor 14 is coated with Tungsten or Molybdenum, each of
22 which have a coefficient of thermal expansion between about 2.5-
23 3.0 micro-strain/F°, while sensor 15 is coated with Aluminum or

1 Magnesium as described in the foregoing discussion. In such a
2 configuration, the difference in the coefficients of thermal
3 expansion of fiber sensors 14 and 15 is between about 11.0 and
4 11.5 micro-strain/F°.

5 In another example, sensor 14 is coated with Tungsten or
6 Molybdenum, as described in the foregoing description, and sensor
7 15 is coated with Lead, which has a coefficient of thermal
8 expansion of about 29.0 micro-strain/F°. Such a relative high
9 coefficient of thermal expansion provides a significant
10 difference in temperature sensitivity between sensors 14 and 15.
11 In this configuration, the difference in the coefficients of
12 thermal expansion of fiber sensors 14 and 15 is between about
13 26.0 and 26.5 micro-strain/F°.

14 It is to be understood that these are just examples and
15 that other material coatings can be used as well. As a result of
16 the different coefficient of thermal expansion values of the
17 material coatings, each of the Bragg grating sensors 14 and 15
18 exhibit a unique and different degree of strain due to
19 temperature while reacting in substantially the same manner in
20 response to non-temperature effects such as hydrostatic pressure,
21 tension, bending, etc.

22 Interface 28 is used to input calibration data into
23 processor 26. Such calibration data includes the diameter of

1 optical fiber 12, the thickness of the material coatings of fiber
2 sensors 14 and 15, coefficients of thermal expansion, and other
3 variations in the properties of these material coatings.
4 Processor 26 uses the calibration data to determine the
5 temperature of the portion of structure 10 at which fiber sensors
6 14 and 15 are located. Since the strain upon each fiber sensor
7 14 and 15 due to non-temperature effects is substantially the
8 same, the difference between the non-temperature strain of fiber
9 sensor 14 and fiber sensor 15 is negligible. In a preferred
10 embodiment, processor 26 is programmed with an algorithm that
11 uses the aforementioned calibration data and which determines the
12 strain upon each fiber sensor 14 and 15 due to both temperature
13 and non-temperature effects.

14 In a preferred embodiment, fiber sensors 14 and 15 are
15 collocated upon optical fiber 12 and are configured to have
16 different wavelengths to facilitate identification of each fiber
17 sensor 14 and 15. However, in another embodiment, the fiber
18 sensors 14 and 15 are configured to have the same wavelengths.
19 In such a configuration, fiber sensors 14 and 15 are sufficiently
20 spaced so as to enable time multiplexing by processor 26. Such a
21 configuration effects averaging of the temperature measurement
22 over a length scale on the order of the fiber sensor spacing. In
23 such a configuration, the length scale is minimized by wrapping

1 optical fiber 12 around structure 10 in a helical formation. The
2 helical formation also limits any bending stress to which
3 structure 10 may be subjected.

4 Thus, the system and method of the present invention
5 achieves the objects set forth above and provides many
6 advantages. Specifically, the system of the present invention:

- 7 a) utilizes sensors that are passive and do not require
8 operating voltage source;
- 9 b) provides accurate and consistent measurements;
- 10 c) can be implemented with a variety of hardware and
11 software systems and components; and
- 12 d) can be implemented at a relatively low cost.

13 While the present invention has been particularly described,
14 in conjunction with a specific preferred embodiment, it is
15 evident that many alternatives, modifications and variations will
16 be apparent to those skilled in the art in light of the foregoing
17 description.

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6 ABSTRACT OF THE DISCLOSURE

7 A system and method is provided for determining the
8 temperature to which a structure is subjected. An optical fiber
9 having at least one pair of fiber sensors is attached to the
10 structure. The fiber sensors comprise Bragg gratings and each is
11 configured to have a particular coefficient of thermal expansion
12 and be responsive to a particular wavelength. A broadband
13 spectrum of light is launched into the optical fiber. The light
14 returning from the fiber sensors is detected. The temperature to
15 which the structure is subjected is then determined based on the
16 difference in strain response of the fiber sensors as a result of
17 the effects of temperature upon the fiber sensors. Coatings of
18 different materials may be applied over the optical fiber to
19 provide the fiber sensors with differing coefficients of thermal
20 expansion.

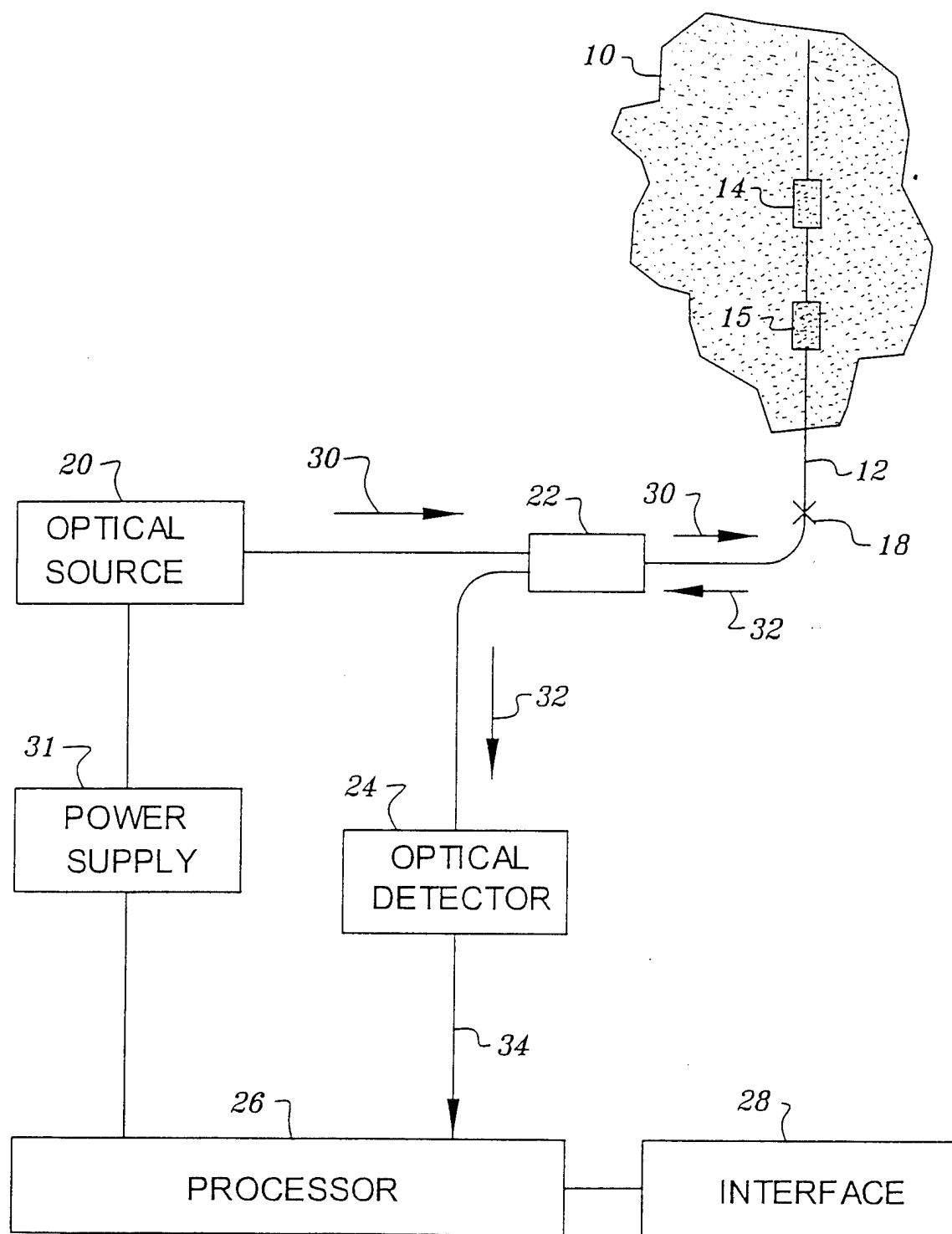


Fig. 1