Temperature Sensing Using Fiber Optics

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ABSTRACT: An optical fiber is a fiber made up of drawing glass (silica) or plastic to a diameter slightly thicker than that of human hair and is flexible and transparent. These types of fibers are used most often as a means to transmit light. This paper designed a multi-channel fiber-optic temperature sensor system (FTSS) using an optical reflectometer (OTDR) for the time domain. The FTSS built consists of fiber-optic temperature-sensing probes, a fiber-optic coupler, an optical fiber transmitter and an OTDR. The fiber-optic temperature sensing probes are composed of silicon oil, a nickel-plated brass seal, a fiber channel (FC) terminator, and an optical fiber single mode. The developed FTSS has four channels connected using single-mode optical fibers of different lengths which have fiber-optic temperature sensing probes. Silicon oil is used as a tool for temperature sensing, because its refractive index varies with the variations in temperature. The paper measured the optical powers of the reflected light signals (Fresnel reflection), which are produced in the distal ends of the sensing probes at the interface between the silicon oil and the center of the single-mode optical fiber. The optical powers of the four FTSS channels were calculated to assess individual temperatures at four different points simultaneously using an OTDR.

KEYWORDS: Fiber-Optic Temperature Sensor, Fresnel Reflection, Optical Time-Domain Reflectometer, Multi-Channel.

INTRODUCTION

A temperature sensor is usually a thermocouple or RTD unit that provides the measurement of temperature by means of an electrical signal. A thermocouple (T / C) is made of two dissimilar metals, which produce electrical voltage in direct proportion to temperature changes. An RTD (Resistance Temperature Detector) is a variable resistor that can precisely, repeatable, and almost linearly change its electrical resistance in direct proportion to temperature changes. There are several different forms but a thermistor is the most common. A thermistor is made of a material that increases temperature resistance and a modified ohmmeter that reads out directly in temperature is used to test the resistance.

A thermocouple is another can form, available even on low-cost mustimeters. A thermocouple is made of two separate forms of wires waved together (or sometimes twisted). The thermistors are typically used up to 100 ° C while the thermocouples are not as reliable for higher temperatures. A fiber optics is a type of fiber made up of drawing glass (silica) or plastic to a diameter slightly thicker than that of a human hair which is transparent and flexible in nature. These optical fibers are used transmit light between the two ends of the fiber and find wide usage in fiber. Optic communication. Temperature is a very significant physical volume in various natural science processes like physics, chemistry, medicine, and biology.

In various industries, such as food and beverage manufacturing, plastic production, and metal manufacturing, temperature monitoring and control is required. Different types of instruments, including thermocouples, resistance temperature detectors, thermistors, infrarot radiation thermometers, and heating labels, can be used to calculate the temperature, depending on their suitability for a specific calculate. It is also possible to calculate the temperature at several points simultaneously, using the same type of temperature measurement devices with the same performance level.

The fiber-optic-based sensor can be used as one of the most appropriate instruments for temperature measurements at several distributed points if the measuring points are located far away from each other. The fiber-optic-based sensor provides many advantages such as small size, good durability, remote control, sensitivity to electromagnetic field and radio frequency interference, and ability to work in harsh environments.

Various fiber-optic temperature sensors have been developed and it has been stated that they may measure temperature using fiber Bragg gratings (FBGs), infrarot (IR) optical fibers, or special materials that can alter their physical characteristics, including color, absorption, and reflectance, depending on the temperature; However, even though they use long optical fibers, the above fiber-optic-based temperature sensors are not appropriate for measuring temperatures at widely spread multiple points. In certain situations, measuring temperatures at points that are hundreds of meters apart or several kilometers apart at the same time is necessary. For example, temperatures in inaccessible dangerous environments like a nuclear power plant, a toxic waste site and a chemical plant need to be measured or monitored.

Because it is versatile and can be packaged because cables, optical fiber is used as a medium for telecommunications and computer networking. This is especially useful for long-distance communications, because infrared light propagates with much lower attenuation compared to electrical cables via the fiber. The optical fiber consists of a center and a cladding layer, chosen for complete internal reflection regardless of the disparity between the two in the refractive index. The cladding is usually coated with a film of acrylate polymer or polyimide in functional fibers. Such coating protects the fiber from damage but does not contribute to the properties of the optical waveguide. Individual coated fibers (or fibers formed into ribbons or bundles) then extrude around them a tough resin buffer layer or core tube(s) to form the center of the cable. Various layers of protective sheathing are applied to form the cable, depending on the application. Rigid fiber assemblies often insert light-absorbing ("dark") glass between the fibers to prevent light from reaching another one that leaks out of one fiber. It reduces cross-talking between the fibers or reduces flare applications in fiber bundle imagery

In this research, a multi-channel fiber-optic temperature sensor system (FTSS) based on silicon oil using an optical time-domain reflector (OTDR) to measure temperature at multiple arbitrary points simultaneously is build. OTDR is an optoelectronic instrument that can be used to identify optical fibers and expose positions of fiber breaks in fiber optic communication networks. OTDR may be used as a light source and as an optical measurement tool as part of the FTSS. It can calculate several different optical signals that are produced at distributed multiple points at the same time as the temperature changes and calculated and analyzed the optical powers of the four FTSS channels to calculate individual temperatures at four different points simultaneously using an OTDR. Figure 1 shows the structure of temperature sensing probe.

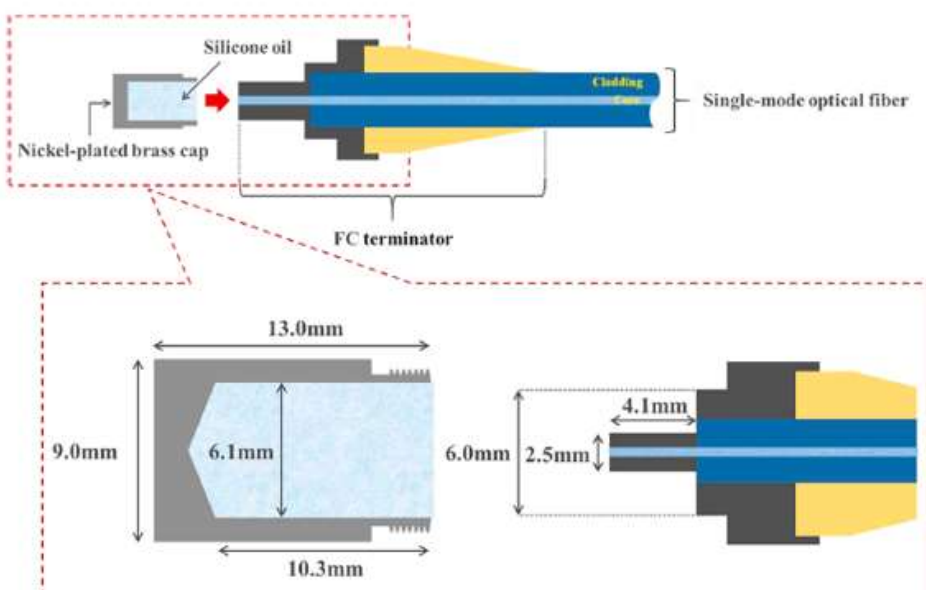

Fig.1: Structrue of the Temperature Sensing Probe

LITERATURE REVIEW

Optical fibers are dielectric waveguides that move between two points of light. Typically made from high-purity lenses. It is well understood that light travels in free space in a straight line, but when light is stuck in an optical fiber, it can spread with bends, and bring information from a few meters to thousands of kilometers away. This property of optical fibers has powered the manufacture for telecommunication applications of low-loss optical fibres. Optical fibers are widely used in many other applications, such as lasers, amplifiers, and sensing[1]. Describe a system for constructing implantable optical fibers that can easily modify neural circuit elements with minimal tissue damage or adjust the light intensity over time (weeks to months). Implanted optical fibers integrate effectively with electrophysiological arrays or electrochemical detection electrodes of in vivo. The protocol outlined here can be completed in about 2-6 weeks, from the implant construction to the start of behavioral testing. Successful use of implantable optical fibers would allow long-term regulation of in vivo mammalian neural circuits which are central to the study of behavioral neurobiology[2]. Some recent developments on optical fibre sensors are mentioned in this review article. Particular mention is made of fiber Bragg grating (FBG), long-term gratings (LPG), evanescent ground, and hollow core optical fiber sensors. Examples of recent optical fiber sensors are briefly defined for measuring strain, temperature, displacement, air flow, pressure, liquid level, magnetic field, and determination of methadone, hydrocarbons, ethanol, and sucrose[3]. The recent developments in polymer technology have allowed the implementation of optical plastic fiber in the design of sensors. The advantages of optical metrology with plastic optical fiber have attracted the scientific community's attention as they enable low-cost or cost competitive systems to be built in comparison with traditional technologies. The latest state of the art of plastic optical fiber technology will be evaluated in this paper, namely its principal characteristics and sensing benefits. This will identify many measurement methods, with a strong emphasis on questioning strategies focused on transmission and reflection intensity variations[4]. This paper explores the fundamentals of producing supercontinuum in optical fibres. Following a brief description on pulse propagation in optical fibers, this paper provide an overview of the various nonlinear mechanisms leading to the generation of supercontinuum broadband spectra with emphasis on the anomalous dispersion rule. There is also analysis of the coherence and statistical aspects[5]. Sensor technology has a huge effect on many facets of our society and has made considerable progress, powered by nanoscience and nanotechnology growth. Present research efforts aim at developing high-performance gas sensors with low operating temperatures at low production costs. Future research insights and current issues needed to be tackled in the area of room temperature sensors are also explored. Gas sensors which work at room temperature have seen significant progress recently. Nanostructured materials with tailor-made structures, a broad surface-to-volume ratio and high surface reactivity display great potential for use as sensor layer[6]. This paper provided a description of piezoelectric sensing techniques at high temperatures. First, it addresses various types of single piezoelectric high-temperature crystals, electrode materials, and their pros and cons. Secondly, recent work on high-temperature piezoelectric sensors including accelerometer, surface acoustic wave sensor, ultrasonic transducer, acoustic emission sensor, gas sensor, and pressure sensor was tested for temperatures up to 1,250 ° C. Ultimately, discussions are being conducted on current issues and future research for high-temperature piezoelectric sensing[7]. This shows a transparent stretchable (TS) gated sensor array with high optical clarity, conformity and high stretch ability of up to 70 percent. The TS-gated sensor array has high sensitivity to changes in object and human skin temperature. This groundbreaking TS-gated sensor array, as well as the integrated TS-gated sensor design with a transparent and stretchable strain sensor, show tremendous potential for application to wearable skin electronics for human activity recognition[8]. Within this paper a Fabry-Perot fiber optic interferometer (FPI) has been proposed and demonstrated. The sensor was constructed by splicing a single mode fiber (SMF) and a hollow core fiber (HCF), cleaning and filling the HCF with polydimethylsiloxane (PDMS) to a duration of 15 ± 1 μm. The sensor tip sensitivity was 0.61 nm/ ° C, and was caused by a combined thermo-optical and expansion coefficients effect. The sensor architecture is evaluated and assessed by the time-domain finite-difference (FDTD) method. The proposed sensor is then produced using traditional single-mode (SMF) fibre. A sheet of gold (Au) and a sheet of nickel (Ni) on the SMF surface are sputtered and electroplated, respectively. A micro-punch-hole is machined as a cavity of the Fabry-Perot (FP) by oriented ion beam (FIB) milling. Here, the FP cavity structure can be viewed as a pair of bimetallic stripes.

METHOD

This paper developed a multichannel FTSS for simultaneous temperature measurements in real time. It consists of fiber-optic sensing temperature probes, a fiber-optic coupler, an optical fiber transmitter, and the OTDR. The temperature sensing probe consists of a sensing material for temperature, a nickel-plated brass hat, a terminator for the fiber channel (FC) and a single-mode optical fiber. A silicon oil is used as the temperature-sensing source, whose refractive index varies with the variations in temperature. This also exhibits temperature control, strong heat transfer characteristics, and is very simple in the −35 ° C to 250 ° C temperature range.

A nickel-plated brass cap with a relatively good thermal conductivity is used to improve the resilience to temperature, and nickel plating can avoid corrosion from external pollutants. The height of a nickel-plated brass cap in a cylindrical shape is 13.0 mm, and the cap's outer and inner diameter is 9.0 and 6.1 mm, respectively. A FC terminator is used for a simple and precise attachment of the optical fiber to the optical instruments (such as OTDR and fiber-optic coupler), which allows fast and easy manipulation with the nickel-plated brass caps due to the spiral structure of the inside groove.

A single-mode optical fiber that has a core / cladding structure to relay the light signals from the temperature sensing probe to the OTDR. The outer diameter of the optical single-mode fiber is 245 μm and is made of fluorinated polymer with a refractive index of 1.402. The heart is 3.6 μm in diameter, and is made of silica, which has a refractive index of 1.46.

OTDR was used in this analysis as a light source and a light measuring instrument. In the field of optical communications it is widely used to calculate the failure points of buried optical lines. It can measure and view a series of optical pulses produced from endpoints along optical fibers by the light that is scattered (Rayleigh backscattering) or reflected (Fresnel reflection). The benefit of the OTDR is that it can test several optical signals simultaneously in real time and expand the range of the optical fiber to several hundred kilometers.

Calculation is done for the reflected light optical power (Fresnel reflection), using the OTDR. The reflection of Fresnel is the reflection of a portion of incident light at a distinct interface between two media with different refractive indices. The Fresnel reflection is produced in the FTSS at the distal end of the sensing probe, at the interface between the silicon oil and the center of the single mode optical fiber. The refractive index of silicone oil decreases as the temperature increases, and approaches the refractive index value of the core of the single-mode optical fiber which causes a decrease in the Fresnel reflection strength. Consequently, the volume of Fresnel reflection increases with the reduction of the silicon oil temperature. The temperature at an arbitrary point can therefore be measured by calculating the light intensity of the reflected light which is directly related to the shift of the silicone oil refractive index. Figure 2 shows the experimental set-up of temperature measurement of water using temperature sensing probe.

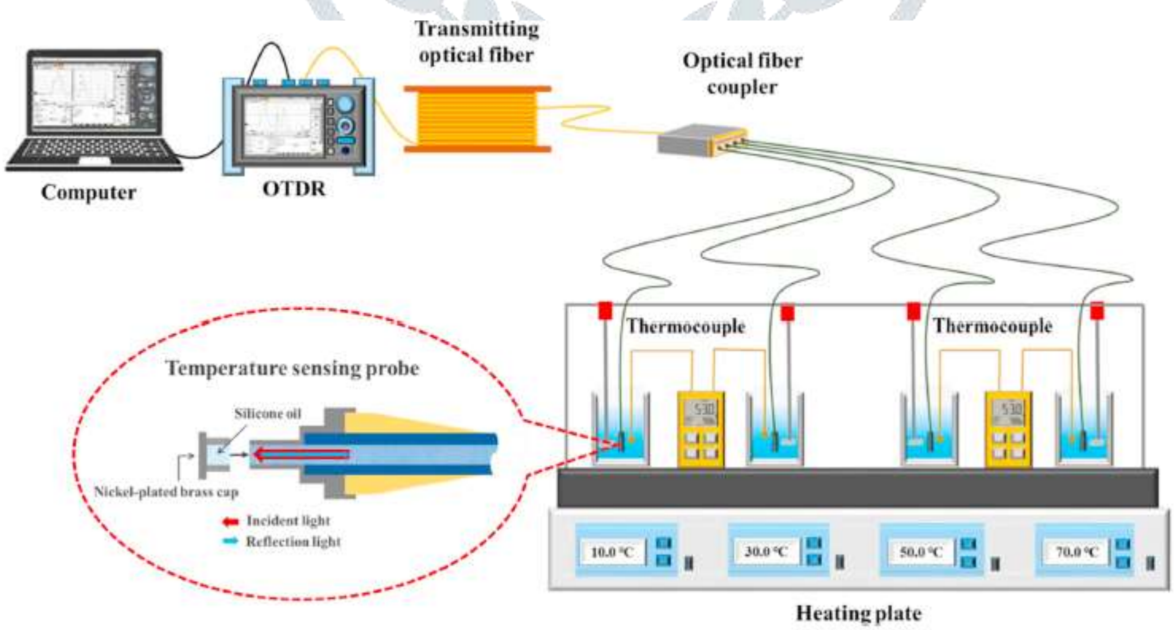

Fig.2: Experimental Setup of Temperature Measurement of Water Using Temperature Sensing Probe.

The experimental system used to test the sensing probe of temperature. Once the four channels, which have temperature sensing probes, were positioned in the four beakers, the water temperature in each beaker was monitored and maintained independently using a heating plate. The water temperature was measured by means of a thermocouple (54II thermometer, Fluke), used as a reference thermometer. To evaluate the water temperatures in the four beakers, the measured temperatures using the thermocouple and optical forces using OTDR in the four channels were compared and analysed. A 1 fiber-optic coupler (FCQ1315-FC) was used to transmit the OTDR optical source signal to the temperature sensing probe and to collect and transfer the Fresnel reflection signals from the samples to the OTDR.

CONCLUSION

This study established a silicon oil based multi-channel FTSS, whose refractive index varies with variations in temperature. The developed FTSS consists of four channels with fiber-optic temperature sensing probes, a fiber optic coupler, an optical fiber transmitter, and an OTDR. The channels 'fiber-optic temperature-sensing probes featured silicon oil, a nickel-plated brass seal, an FC terminator, and an optical single-mode tube.

OTDR was used to calculate the optical power of the reflected light signals from the temperature- sensitive probes. They relied on the channel temperature fluctuations, and were analyzed to assess the efficiency of the FTSS. Furthermore, the relationships were established between the measured optical power and temperature, which can be used to calculate temperature values at desired points. The results obtained show that the proposed FTSS can reliably measure temperature in the 10–70 ° C range, and can be used in real-time as a multichannel temperature sensor. As a result, we verified that the FTSS has good reproducibility and that the response time is between 47 and 48 sec, and the sensing time per degree Celsius could be measured as around 0.79 sec/ ° C. If the sensing probe is designed with a cap that has a smaller size and higher thermal conductivity, the response time may be reduced. However, making a proper cap was very difficult, and it was not commercially available. Based on the results of this analysis, the proposed multi-channel FTSS may be used to track temperatures effectively over a long distance as industrial applications, and can be used in chemical or power plants in particular.

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