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Positioning and Temperature Optical Fiber sensors and application

Physics

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ABSTRACT

In the report given, there are both temperature and positioning fiber optic sensors that are discussed. Throughout this paper there will not be a complete overview of all fiber optic sensors, but the basics of a fiber optic sensor will be explained. I will discuss different ways to measure the temperature, along with positioning. Both of these fiber optics have many uses in today's world, and many examples will be given for their applications.

Fiber Optic Sensors

In today's world, there are two main types of fiber optic sensors being used. These sensors can be classified in several ways, but one of the ways to classify them would be intrinsic or extrinsic. For the intrinsic sensor, the fiber is directly affected by the measurement, in other words, the fiber is the sensing element itself. These intrinsic sensors can be used to measure temperature, pressure, strain, and other quantities by modifying a fiber so that the quantity to be measured will modulate the phase, polarization, intensity, and wavelength to transmit the time of a light in the fiber. These sensors are considered to be the simplest, mainly because only a detector and a simple source are needed. For the temperature to be measured by the intrinsic sensor, it must use a fiber that has an evanescent loss that will vary with the temperature, or another way to be to analyze the Raman scattering of the fiber. For the sensor to measure collocated temperature and strain simultaneously with high accuracy, it must use fiber Bragg gratings. These are mainly used when needing to obtain information from small complex structures. Extrinsic sensors on the other hand, us an optical fiber cable to transmit modulated light from either an electronic sensor connected to an optical transmitter, or a non-fiber optical sensor. The benefit of using these extrinsic sensors is that they are able to reach usually inaccessible places. These fiber optic sensors provide outstanding protection of the measurement signals against noise corruption. These sensors are used to measure vibration, rotation, velocity, torque, twisting, displacement, and acceleration.

Another way to classify these fiber optic sensors is phase modulated and intensity modulated. The phase modulated sensors compare the phase of the light in the sensing fiber with a reference fiber in the interferometer. While the intensity modulated sensors will let a physical disturbance cause a change in the light being received through the optical fiber. Out of these two kinds, the phase modulated sensors are highly more accurate, but are also much more expensive because of the advanced electronics that have to be provided for the interferometer information.

Intensity Modulated Sensors

This section will go more in depth with the intensity modulated sensors. These sensors must change the intensity of the light being measured into a predictable output. There are a few ways that this can be done. This can be done by the use of micro bending intrinsic sensors, or by using the concept of transmission or reflection. For the micro bending technique, the optical fiber is bent in which there will be small amounts of light lost from the angle of incidence of the transmitted light and the optical fiber's walls due to the total internal reflection loss. This concept will detect a displacement in a closed optical path, and this path is usually in an environment that is not clean. The concept of transmission or reflection typically works by moving the detector a certain distance away from the optical fiber center. This is usually used as a digital switch or a similar detector.

The advantages of the intrinsic sensor over the phase modulated sensor, is that the intensity has the ability to be changed without and movement of the fiber. To fix that problem, the intrinsic sensor changes the refractive index in the core glass, which is absorption through the fiber optic walls or polarization to change the intensity. Some of the main measurements for these sensors are pressure and temperature.

Phase Modulated Sensors

For the phase modulated sensors, they typically consist of a coherent laser that injects light into two single mode fibers. These sensors are very accurate, and are able to detect very small phase shifts to accommodate this. For example, if an environment detects one or both of the single fibers differently, that phase shift will be detected.

Fiber Optic Sensors for Positioning

History

The fiber optic position sensor has not been out very long. The first fiber optic positioning sensor was introduced in 2011. These sensors are immune to any electro-magnetic interference. For example they are immune to radiation, lightning, magnetic fields and many other environmental conditions that are considered harsh. They are mainly used for long distance position sensing, over three hundred meters, in which they will not be affected by ground loop problems. They are also able to measure absolute angular position from 0 degrees to 360 degrees with speeds exceeding 2500 rpm.

Positioning Sensor Use Fiber optic positioning sensors use an optical technique which is embedded in a passive sensor and an active controller connected by a duplex fiber optic link. The controller with then transmit a burst of light to the code disk, which is similar to a bar code with dashes of mirrored metal stripes. The disk will then turn and each sequence of code is different, so there will be a unique code at every position while the disk moves. On that disk, only at specific wavelengths will the bars reflect the light and only certain colors of the light are returned over a separate fiber optic cable to the controller. Inside that controller, the light is then dissected and analyzed for the wavelength and the result is ready in binary digital form. The light is then kept stable in the controller by constantly monitoring the light source and trying to detect any movements. The light source will generally pulse at a very short duration, 10 micro seconds. This time duration was needed because generally the system will take a snapshot of its actual position and it will pulse the light at 800 micro second intervals. An example of a positioning sensor is shown in Figure 1.

Fig.1-Fiber optic positioning sensor

Fiber Optic Temperature Sensors

Fiber optic temperature sensors consist of both extrinsic and intrinsic to measure temperature. There are many ways to classify these sensors as well They can be classified due to their nature which would include interferometric sensors, wavelength encoding, resonant sensors, distributed, or even intensity ratio based devices. They may also be characterized by its modulation used for encoding the temperature information. 3.1 Examples of Temperature Sensors A very basic type of fiber optic temperature sensor has been around since 1985. This concept would put the fiber into a capsule at the reflecting surface. Then on the other side of the surface there would appear an air bubble. The bubble would fluctuate based on the temperature. This allowed the thermo sensitive cladding of the fiber to either contract or expand. Along with the cladding changing, the attenuation of light in the fiber and the numerical aperture would has have change due to the temperature. This sensor, even being from 1985 was able to obtain a sensitivity of better than 0.1 degrees Celsius. The pro about this design is that in medical or biological applications, the temperature range is very narrow allowing them to use this low cost design showed in Figure 2. But, the con of this design is that the temperature sensing range is very limited in which many other applications around the world would not be able to use this design.

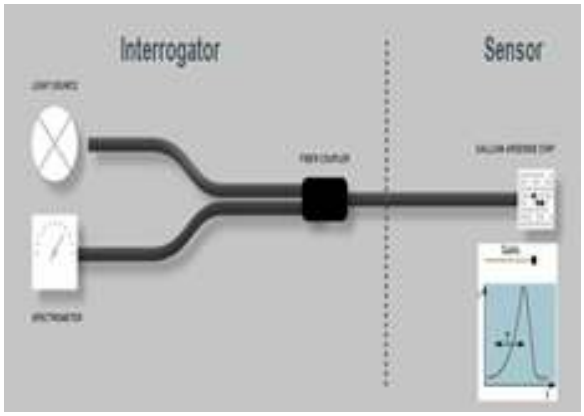
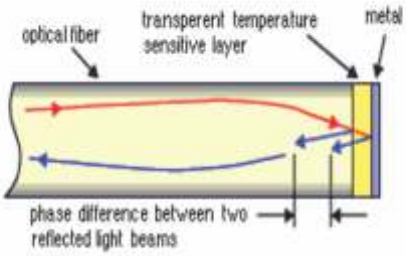


Fig-2 optical fiber temp.sensor

For the second type of fiber optic temperature sensor, there is the interferometric sensor. This sensor is a technique used in almost any type of physical quantity measurement. Interferometry itself will yield very high resolution measurements of length, and fiber optic techniques have been created to where a certain measurand can be converted into a displacement change. High precision measurements are exactly what the fiber optic interferometers are best at, when it comes to measuring temperature. There are also several different types of the interferometers: Mach-Zender, Michelson, Sagnac, and Fabry-Perot. These interferometric sensors work by sending a light through a reference fiber and also a sensing fiber. As the temperature changes the physical dimensions of the sensing fiber, there would then be a phase difference in between the light while it travels between the two fibers previously stated. That phase difference can be measured by transforming into a physical dimension change, and lastly it will give the temperature information needed. This phase difference is shown in Figure 3.



Fiber Optic Temperature Sensor Using Phase Interference

Another type of fiber optic temperature sensor is the Fabry-Perot temperature sensor. A FabryPerot sensor was created in the early 1990's. This sensor generally uses an LED as a light source. This LED, which is a low coherence source, was in competition with using a semiconductor laser, but the low coherence source does not need to compensate for shifts in the emission wavelength of the laser that are thermally induced. Also, it is not limited to select the device for a single-mode operation, and lasers are much more expensive than the LED's. The only downfall of using the LED's is that there will be much less sensitive. The sensor itself generally uses two Fabry-Perot interferometers, and there is one used as a reference sensor along with a sensing sensor. The light from the LED is modulated by reflection, and the order is that the sensing sensor goes first as it senses the Fabry-Perot interferometer followed by the reference sensor. The equation used to show that the power output is proportional is (1 + 0.5cos p) in which p is considered the phase shift due to the minor change from a physical state applied to the interferometer. Generally the phase shift is inearly dependent on the temperature range from 26 degrees to 108 degrees Celsius. Also, with using the two Fabry-Perot interferometer sensors, the sensitivity will be smaller than that of a single Fabry-Perot interferometer sensor when using a laser source. In fig. 4 an SEM photo shows a micro fiber-optic Fabry-Perot interferometric (MFFPI) sensor (a). Its reflective spectrum (b), strain characteristics (c), and temperature response (d) are shown at different temperatures.

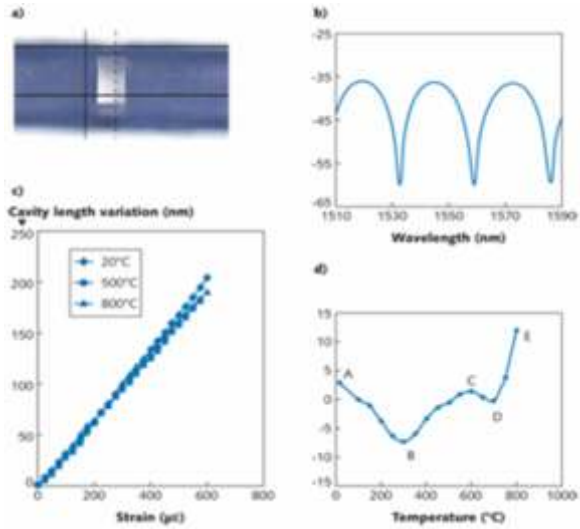


Fig-4 An SEM photo shows a micro fiber-optic Fabry-Perot interferometric (MFFPI) sensor (a). Its reflective spectrum (b), strain characteristics (c), and temperature response (d) are shown at different temperatures.

Applications of Temperature Sensors

There are many applications in today's world that need and use fiber optic temperature sensors. These applications include:

- Smart grid temperature monitoring of transformer winding hot-spot Generator stator temperature Bus-bar temperature monitoring
- Smart grid switch gear temperature monitoring
- High voltage cable and transmission line monitoring
- Fuel cell temperature control
- Electrostatic chuck temperature for conductor or dielectric etch processes
- Silicon wafer temperature and wafer mapping for process control
- Microwave temperature sensing
- Magnetic Resonance Imaging, MRI temperature monitoring
- X-Ray transparent temperature sensing
- Temperature sensors for inductive heaters
- Plasma temperature measurement
- Shielded thermocouple and RTD applications

Switch Gear Temperature Monitoring

Fiber optic temperature sensors can provide continuous real-time monitoring of switch gear temperature at very critical contact points that will detect over-load and fault conditions as soon as they occur. These sensors provide real-time temperature data, which enable the operators to maximize the load efficiency and also balance the thermal stresses that can and will lead to failures. Once time goes by after installation of the switch gear contacts, critical connection points, and bus bars develop hot spots. These hot spots will slowly corrode away which causes increased electrical resistance. There are other possibilities for companies to use that include radiofrequency (RF) wireless and infrared thermometers. But the RF transmitter and receiver both have to deal with inherent noise and interference from the high voltage environment. This will lose signal and show temperature spikes during the switch operations which will create false alarms. The remote infrared temperature sensors are similar because they need the electrical wiring to be shielded and the mounting points to be precisely spaced to the objects surface being sensed. These infrared thermometers have been reported to actually report a temperature change because of the dust accumulation and emissivity changes due to corrosion like that of the copper bus bars.

Fiber optic temperature sensors do not pertain to any of those technical difficulties dealing with wireless and infrared thermometers. These sensors can be routed directly to the switch gear's critical monitoring spots. Also, they are completely resistant to the electromagnetic interference and bursts of noise created by high voltage switching.

Transformer Winding Hot Spot Temperature Monitoring

The fiber optic temperature sensors are completely immune to the EMI, RFI, and high voltage environments which make them very reliable for transformer winding and hot spot temperature monitoring. These sensors have been installed into oil filled high voltage transformers for over twenty years and in today's world they are preferred to be used. For these sensors to work, optical temperature probes are designed from high-dielectric strength materials so that they will be able to withhold long term immersion in transformer oil and also during its manufacturing in kerosene. There is a tank wall feed through that is used to transmit the fiber's sensor signal from the optical temperature transmitter to the probe that is installed directly at the winding hot spot locations. There are also sensor signal conditioners mounted in an external control cabinet the temperature outputs fed to control software. The operators can then monitor the load conditions which will reduce waste energy production.

Conclusion

During this report, there were discussions on several different types of fiber optic sensors. It seems that these fiber optic sensors can be used to measure almost any physical quantity, with many ways to do it. The many ways also showed concepts and sensors that were much cheaper than others but also had a lower sensitivity, while some of the higher sensitive ones were expensive. The temperature sensor was shown to be very useful in today's world, mainly because of all the applications it can be used in. It has made itself into a need rather than just an option for some companies. Overall, fiber optic sensors are making their place in this world, and will soon be found everywhere.

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