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FIBER OPTIC DISTRIBUTED BRILLOUIN SENSORS

Features

- Simultaneous measurement of temperature and strain
- Yields high resolution data along the entire length of fiber sensor
- High spatial resolution
- Extremely long sensor range (up to 80 km)
- Standard communications fiber is used. The same fiber could be used for both sensing and communication

Applications

- Corrosion monitoring of large structures
- Oil and gas pipeline monitoring
- Oil and gas well monitoring
- Liquefied natural gas (LNG) pipeline monitoring
- Bridge and dam strain monitoring
- Smart structures and structural health monitoring (SHM)
- Security systems
- Defense equipment and border security
- Power line monitoring

Description

OZ Optics offers a sophisticated sensor system using Brillouin scattering in optical fibers to measure changes in both temperature and strain along the length of an optical fiber. By wrapping or embedding a fiber inside a structure such as an oil pipeline or dam, one can detect when the structure is being strained or heated, and correct the problem before failure occurs. Such monitoring capability is invaluable in critical structures where failure could represent loss of lives or millions of dollars.

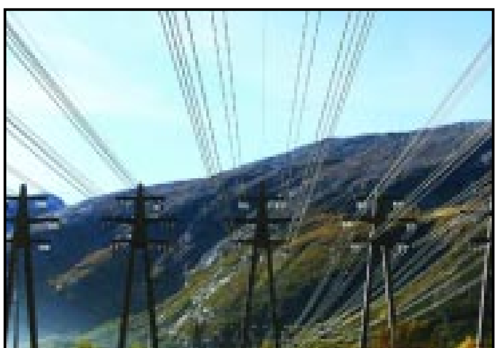
Another application of these sensors is for alarm systems. A sensor system in a field or building perimeter can sense distortions caused by an intruder. A low resolution version of the system makes this application practical and relatively inexpensive.


Oil and Gas Pipeline Monitoring


Dam Monitoring


Oil and Gas Well Monitoring


Bridge and Building Monitoring


Power Line Monitoring


Border Security Monitoring

The sensing technology gives both temperature and strain readings along the length of the fiber, with spatial resolution as short as 5cm. Being able to monitor both temperature and strain changes is a key advantage, as it allows one to identify which changes in the strain on the fiber are temperature related, and which are caused by outside stresses.

Depending on the configuration selected, systems with measurement ranges as long as 60km can be provided. One can use such a setup to monitor a very long length device, like a pipeline or highway, or lay the fiber to form a 2D or 3D grid in a structure, forming a large smart structure in a device like a dam wall or submarine hull.

One additional feature of the system is that it can be configured for wireless communication, using the technology found in our *Smart Patchcords And Wireless Fiber (Patent Pending)*. This allows the system to be installed in remote locations or moving vehicles where conventional communications are unavailable, and transmit the information to a central monitoring system.

Please Contact OZ with your pipeline, perimeter and structural monitoring requirements.

The OZ Optics Brillouin sensor system is packaged in a rugged field housing for convenient deployment to the field.

Specifications:

Fiber Optic Distributed Brillouin System	
Parameter	**Value***
Technology	BOTDA
Configuration	Loop
Range	80 km
Spatial Resolution (SR)	10 cm
Distance Resolution	10 cm
Strain resolution	6 micro-strain
Temp resolution	0.5C
Acquisition Time	Application specific
Averages	User selectable
Communications	TCP/IP
Remote operation	Yes
Temperature Range	0-40C
Simultaneous Temperature/Strain	Yes

* These specifications reflect the best attainable value for each quantity and may not be simultaneously achievable. For cost efficiency, the OZ Brillouin sensor system has a modular design, and not all specifications are achievable with every modular configuration. Please contact OZ with your application requirements.

Related Products

OZ-Guard™ Fault Finder

The OZ-Guard™ Fault Finder is an OTDR-based product that detects and locates breaks or major bends in fiber optic cables. OTDR-based monitoring is an excellent low-cost complementary technology and gives pipeline operators even more reason to consider fiber optic monitoring. The OZ-Guard™ Fault Finder offers the best value of any product in this segment. Although the OZ-Guard™ Fault Finder is primarily intended for optical telecommunications network health monitoring, it can also be used to detect and locate major pipeline incursions or other major structural failures. For applications that do not currently justify the cost of a state-of-the-art Brillouin system, the OZ-Guard™ Fault Finder enables low-cost detection and location of major pipeline accidents or other structural failure incidents that cause breaks or severe bends in a fiber optic sensor probe. Our Fault Finder can locate events up to 20 km. For distances up to 80 km, please contact OZ Optics with your requirements.

Because OZ Optics' Fiber Optic Distributed Brillouin System uses standard optical telecommunications fiber as the sensor element, the OZ-Guard™ Fault Finder is interchangeable with our Brillouin system. This provides users with additional flexibility and a choice to deploy continuous monitoring systems on a wider variety of pipelines and structures. Another deployment option is continuous monitoring with OTDR-based devices and periodic surveys with our full-featured Brillouin system. The combination of Brillouin structural monitoring and OTDR-based major event detection makes fiber optic monitoring the most powerful - **and economical** - choice for your pipeline. Please contact OZ Optics to receive a competitive proposal for your pipeline or structural monitoring project.

Fiber Optic Sensor Probes, Components, Termination Kits, and Training

OZ Optics offers a full spectrum of fiber optic sensor probes, components, termination kits and training. OZ Optics' standard fiber optic products have been used worldwide in high performance sensor and telecommunications applications since 1985. OZ Optics also offers specialty fiber optic sensor probes and custom cabling for high temperature applications and other hostile and corrosive environments. System integrators with experience in structural and pipeline monitoring will find that OZ Optics offers a complete suite of enabling products and services for installing and maintaining fiber optic systems. If you are planning a pipeline or structural monitoring project, please contact OZ Optics to learn more about our fiber optic solutions.

For more information about our Brillouin sensor system and related products, please visit www.ozoptics.com.

Applications Of Fiber Optic Distributed Brillouin Sensors

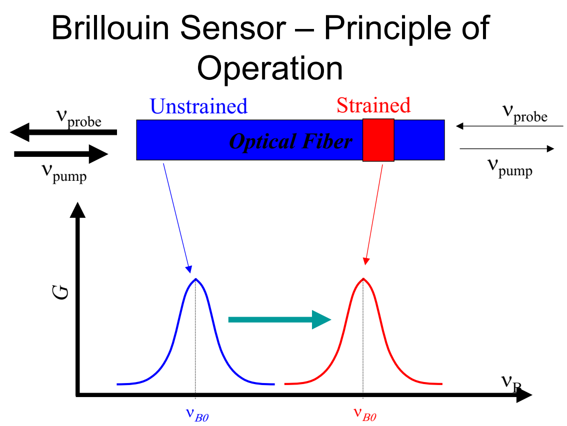
Executive Summary

Distributed Brillouin fiber optic sensors measure strain and temperature over very long distances and are an excellent tool for monitoring the health of large structures. These sensors leverage the huge economies of scale in optical telecommunications to provide high-resolution long-range monitoring at a cost per kilometer that cannot be matched with any other technology. Today's distributed Brillouin fiber sensors offer clear cost and technical advantages in applications such as pipeline monitoring, bridge monitoring, dam monitoring, power line monitoring, and border security / perimeter monitoring. Brillouin sensors are excellent for the detection of corrosion in large structures.

Working Principles

Although a detailed understanding of Brillouin sensors is not required when using OZ Optics sensor systems in typical structural health monitoring applications, a description of the basic measurement will be useful to users who want a better understanding of the specification tradeoffs when selecting a Brillouin sensor system solution.

The most common type of Brillouin sensor uses a phenomenon known as stimulated Brillouin scattering. The measurement is illustrated in the figure below:



$$\nu_{Bs} = \nu_{B0} + \alpha T + \beta \varepsilon$$

Figure 1: Brillouin spectral peaks from strained and unstrained fibers.

The typical sensor configuration requires two lasers that are directed in opposite directions through the same loop of fiber (one laser operating continuously, the other pulsed). When the frequency difference between the two lasers is equal to the "Brillouin frequency" of the fiber, there is a strong interaction between the 2 laser beams inside the optical fibers and the enhanced acoustic waves (phonons) generated in the fiber. This interaction causes a strong amplification to the Brillouin signal which can be detected easily and localized using an OTDR-type sampling apparatus. To make a strain or temperature measurement along the fiber, it is necessary to map out the Brillouin spectrum by scanning the frequency difference (or "beat" frequency) of the two laser sources and fitting the peak of the Brillouin spectrum to get the temperature and strain information.

As the equation at the bottom of figure 1 shows, the Brillouin frequency at each point in the fiber is linearly related to the temperature and the strain applied to the fiber. In some optical fiber known as dispersion-shifted fiber (or LEAF fiber), there are actually two peaks in the Brillouin spectrum and it is possible to extract both temperature and strain information from a single fiber.

Calculating the Cost Savings for Brillouin Fiber Optic Sensors

As stated previously, Brillouin fiber sensors offer high-resolution long distance coverage for structural monitoring at a cost per kilometer unmatched by any other measurement technique. This creates the opportunity to generate a rapid return on investment for Brillouin sensor-based monitoring systems used in critical structural monitoring applications. The figure below shows a simple cost savings example:

Fiber Optic Monitoring
OZ Optics Ltd. Cost Savings Calculator

System Parameters	
Pipeline Length	50km
Cost of Failure	$750,000 cost of leak
Downtime cost	$20,000 per hour

Comparison		**Monitoring**	No Monitoring	Comments
Probability of Failure	%/year	**0.25%**	1%	Reduced risk of failure
Downtime	hours/year	**4.8**	24	Automated preventive maintenance
Maintenance Cost	dollars/year	**$25,000**	$50,000	Automation of routine maintenance
Total Annual Savings		**$414,625**		total annual savings

Figure 2: A simple cost savings estimate for a 50 km pipeline

The most important factors in a typical cost savings estimate are the reduction in maintenance/inspection cost (due to automated monitoring), the reduction in downtime, and the reduction in the potential for catastrophic failure. In many instances, the downtime and failure costs are much higher than that shown in the example.

Several recent pipeline shutdowns demonstrate the need for real-time monitoring. While the calculation in figure 2 is for a mid-sized regional distribution pipeline, the economics for major pipelines are even more compelling. The shutdown cost per day can easily exceed $10 million. With long-haul Brillouin monitoring system costs of only $1-$2 per meter, the prevention of a single shutdown greatly exceeds the installation and operating costs of a real-time monitoring system. Other large structures such as power distribution lines, dams, and bridges also have very high costs associated with catastrophic failure and shutdowns.

To obtain a spreadsheet version of this cost saving calculator or request a customized version for your structural health monitoring application, please contact us.

A Comparison of Fiber Optic Sensor Technologies for Structural Monitoring

Brillouin fiber optic sensors excel at long distance and large area coverage; in fact, Brillouin sensors should be considered for any strain or temperature application with a total length of 1km or more. Another common fiber optic sensor technology appropriate for localized measurements is known as fiber optic Bragg grating sensors. However, for structural health monitoring, when the potential damage or leakage locations are unknown, it is difficult to pre-determine the places to put Bragg grating sensors or strain gauges. Bragg grating sensors are an excellent localized sensor when the specific area(s) of interest are known. Distributed Brillouin sensors can be used for much broader coverage and can locate fault points not known prior to sensor installation.

There are two types of Brillouin fiber optic sensors. Brillouin Optical Time Domain Reflectometers (BOTDR) resolve the strain or temperature based Brillouin scattering of a single pulse. Brillouin Optical Time Domain Analysis (BOTDA) uses a more complicated phenomenon known as Stimulated Brillouin Scatter (SBS).

The BOTDA technique is significantly more powerful as it uses enhanced Brillouin scattering through two counter-propagating beams. Due to the strong signal strength the strain and temperature measurement are more accurate. In addition, the two Brillouin peaks generated in LEAF fibers provide both temperature and strain information simultaneously.

The BOTDA method requires more optical components and a 2-way optical path so the total system cost is typically higher (the sensor fiber must be looped or mirrored). However, most field units deployed today are BOTDA systems because the additional measurement accuracy more than justifies the moderate increase in system cost.

Table 1 provides a comparison of common fiber optic strain and temperature sensor techniques, along with typical performance limits for each type:

	Bragg Grating*	BOTDR	BOTDA
Strain Resolution	1 µstrain	3 µstrain	6 µstrain
Strain Accuracy	1 µstrain	30 µstrain	20 µstrain
Distance Res.	0.1 m	1 m	0.1m
Length Range	Point Sensor	80 km	80 km
Acquisition Time	10s	0-20 minutes	0-20 minute
Configuration	many fibers	single fiber	loop
Temperature Accuracy	0.4C	N/A	0.5C
Temperature & Strain	multiple fiber	multiple fiber	Single fiber
Distributed	No	Yes	Yes
*quasi-distributed with multiple fibers			

Table 1: Typical Specifications for Fiber Optic Sensors

The simultaneous measurement of temperature and strain is possible by using dispersion-shifted LEAF fiber. Like singlemode fiber (or SMF), LEAF fiber is used in large quantities for high speed optical telecommunications networks and is very inexpensive. It is important to make a decision on the fiber type early in any structural monitoring project. Although test equipment can be changed or upgraded in the future, it is essential to install the correct fiber type if the simultaneous measurement of temperature and strain is ever required.

OZ Optics is now collaborating with a major research university to bring new technologies to market that will expand the market for Brillouin fiber sensors through performance enhancement and cost reduction. To get more information on how these technologies may benefit you, please contact us.

Major Applications of Brillouin Fiber Optic Sensors

Brillouin fiber sensors have been applied in numerous applications. As mentioned previously, Brillouin-based systems are generally unmatched in applications that require high-resolution monitoring of large structures (very long, or very large surface areas). Unlike competing sensor technologies, Brillouin systems directly leverage the economies of scale from the millions of kilometers of fiber optic telecommunications fiber installed worldwide. As Table 2 shows below, the most common applications for Brillouin fiber sensors do involve very large linear or spatial dimensions.

Application	Strain	Temperature	References available upon request by OZ Optics collaborators
Bridge Monitoring	■	■	■
Pipeline Monitoring	■	■	■
Process Control	■	■	■
Structural Health Monitoring (concrete & composite structures	■		■
Security Fences	■		
Power Lines	■		
Fire Detection	■	■	■

Table 2. Applications of Brillouin Fiber Optic Sensors

OZ Optics is committed to delivering solutions in each of the markets listed above. If your critical monitoring application is not listed in the table, please contact us with your requirements. To get more detailed information related to your application or request a reference article, please click here.

Background Articles

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