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FIBER OPTIC DISTRIBUTED STRAIN AND TEMPERATURE SENSORS

(USA Patent #: 7499151 and 7599047)

Features:

- Uses standard telecom fibers for simultaneous measurement of temperature and strain.
- Real-time measurement of strain and temperature
- BOTDA and OTDR and/or BOTDR features all in one device
- High spatial, strain, and temperature resolution and accuracy
- Up to 100 km round-trip sensing range
- Multiple channel monitoring
- Real-time fault point detection

Applications:

- Oil and gas pipeline monitoring
- Power line monitoring
- Oil and gas well monitoring
- Corrosion/Erosion monitoring of pipelines
- Crack detection
- Fire detection
- Smart structures and structural health monitoring (SHM)
- Bridge, dam, and building monitoring
- Security monitoring

Description:

OZ Optics' Foresight™ series of fiber optic distributed strain and temperature sensors (DSTS) are sophisticated sensor systems 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/cooled, 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.

While accurate measurements of small strain and temperature variations may require several minutes, the OZ Optics system can detect and report larger signals within one second, with only a slight loss of accuracy. This sort of response speed is required for security applications, or strains caused by earthquakes, where an immediate measurement and response may be required.

See our technical paper on **Pipeline Buckling Detection**.

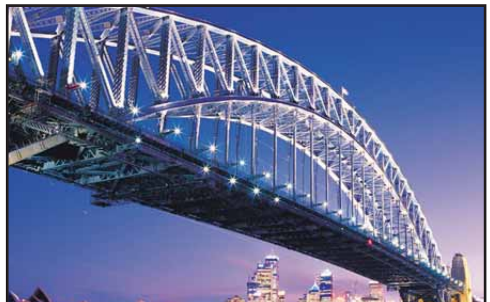
Oil and Gas Pipeline Monitoring

See our technical paper on **Crack Detection**.

Dam Monitoring

See our technical paper on **Pipeline Corrosion Detection**.

Oil and Gas Well Monitoring



Bridge and Building Monitoring

See our technical paper on **Power Line Monitoring**.

Power Line Monitoring

Border Security Monitoring

See our technical paper on **Crack Detection**.

Highway Safety Monitoring

Building Fire Detection

Detecting cracks in structures is a major challenge: only a specialized tool can find the target, and the highest resolution is required to take its measurement. OZ Optics' Foresight™ series of sensors offers our customers a powerful tool to detect cracks on ceramics, concrete beams, dams, and so on.

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

The sensing technology gives both temperature and strain readings along the length of the fiber, with spatial resolution as short as 10 cm. Unlike competing products which cannot tell the difference between externally applied strain and temperature induced strain, the OZ system is capable of measuring both parameters simultaneously, allowing regions of temperature induced strain to be identified.

Depending on the configuration selected, systems with measurement ranges as long as 100 km round-trip 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.

Version F

Version R

Specifications:

	Model		Foresight™ Series			
			DSTS-F-1/2-1	DSTS-F-1/2-0.1	DSTS-R-1/2-1	DSTS-R-1/2-0.1
Performances	Number of Channels		1 or 2			
	Sensor Configuration		Standard is BOTDA loop but optional single ended BOTDR is also available upon request.			
	Sensing Range		100 km round-trip			
	Spatial Resolution		1 m to 50 m	0.1 m to 50 m	1 m to 50 m	0.1 m to 50 m
	Spatial Accuracy		as low as 5 cm			
	Dynamic Range		30 dB	25 dB	30 dB	25 dB
	Number of Distance Points		20 per meter			
	Temperature Range		-270°C to +800°C (depending on cable material)			
	Strain Range		-2% (compression) to +3% (elongation) (depending on cable material)			
	Temperature Resolution		0.005 °C*			
	Temperature Accuracy (2σ)		± 0.1 °C (Whole sensing range for BOTDA)			
	Strain Resolution		0.1 με*			
	Strain Accuracy (2σ)		± 2 με (Whole sensing range for BOTDA)			
	Acquisition Time (full scan)		as low as 1 second			
	Averaging		1 to 10,000 scans			
	Fault Point Detection	Acquisition Time	1 millisecond			
		Distance Range	100 km			
	Simultaneous Measurement of Strain and Temperature (using patent pending cable design)	Temperature Resolution	0.005 °C*			
		Temperature Accuracy (2σ)	± 0.1 °C (Whole sensing range for BOTDA)			
		Strain Resolution	0.1 με*			
		Strain Accuracy (2σ)	± 2 με (Whole sensing range for BOTDA)			
		Sensing Range	50 km			
	Measured Variables		Strain and/or temperature, Brillouin spectrum			
	Graphical Interface		SVGA 17" color screen		SVGA 17" color screen (optional)	
	Communication & Connections		Ethernet port, USB			
	Output Signals		Software alarms via TCP/IP, SPST, SSR relays (optional)			
	Data Storage		Internal hard disc (80GB or more)			
	Data Format		Database, text files, MS Excel, bitmap plot			
	Optical Connections		FC-APC, E-2000			
	Laser Wavelength		1550 nm band (Class 3B type)			
	Operating Temperature		0 °C to 40 °C			
	Power Supply		115 or 230 VAC; 50-60Hz; max 300W			
	Dimensions (L x W x H)		22" (560 mm) x 27" (690mm) x 22" (560mm) (field-ready package)		18.5" (470 mm) x 17" (430mm) x 10.5" (270mm) (Rugged carry-on housing optional)	
	Weight		< 60 kg (including a rugged field housing)		< 28 kg	
Features	Measurement Modes		Manual or automatic unattended measurements			
	Data Analysis		Measurement analysis, Multiple trace comparison with respect to selectable baseline, Measurement trends, Graphical zoom.			
	Alarm & Warnings		Automatic alarm triggering, configurable alarm settings (heat, deformation, etc.)			
	Remote Operation		Remote control, configuration and maintenance via TCP/IP			
	Watch Dog		Long term operation 24/7 guaranteed by automatic recovery and continuous self diagnostics			

* This value is estimated/calculated from the uncertainty of laser beat frequency, 5 kHz, and temperature and strain coefficients of fibers.

Related Products

OZ-Guard^{TM} Fault Finder

The OZ-Guard^{TM} 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^{TM} Fault Finder offers the best value of any product in this segment. Although the OZ-Guard^{TM} 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^{TM} 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 100 km, please contact OZ Optics with your requirements.

Because OZ Optics' Foresight™ series of DSTS uses standard optical telecommunications fiber as the sensor element, the OZ-Guard^{TM} 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 strain and temperature sensor system and related products, please visit www.ozoptics.com.

Applications of Fiber Optic Distributed Strain and Temperature Sensors

Executive Summary

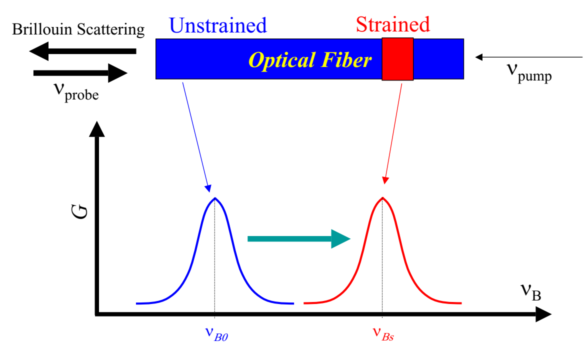
Fiber optic distributed strain and temperature sensors measure strain and temperature over very long distances and are an excellent tool for monitoring the health of large structures. These sensors leverage the huge economies of scale in optical telecommunications to provide high-resolution long-range monitoring at a cost per kilometer that cannot be matched with any other technology. Today's distributed strain and temperature 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 Principle

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 sensor system solution.

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

Brillouin Sensor – Principle of Operation



$$\nu_{Bs} = \nu_{B0} + C_T(T - T_0) + C_\varepsilon(\varepsilon - \varepsilon_0)$$

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 fibers such as dispersion-shifted 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. If one uses the sensor system with our patent pending sensing fiber, then one can simultaneously measure strain and temperature, while utilizing the same fiber for telecommunications.

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 total lengths in excess of 10 meters. Another common fiber optic sensor technology appropriate for localized measurements is known as fiber 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 fiber Bragg grating sensors or strain gauges. Fiber 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).

For Stokes scattering (including Brillouin scattering and Raman scattering) only a small fraction of light (approximately 1 in 10^3 photons) is scattered at optical frequencies different from, and usually lower than, the frequency of the incident photons. Based on BOTDR technology, since the intensity of a backscattered Brillouin signal is at least $1/10^3$ less than that of the incident light, the Brillouin scattering signal is very weak. Considering the attenuation of the optical fiber, for example, 0.22 dB/km, the measurement range cannot be very long and SNR is generally worse than that found with BOTDA technology. The primary advantage of BOTDR technology is that only one end of the fiber needs to be accessible.

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 measurements are more accurate and the measuring range is longer than that of BOTDR technology. In addition, our patent pending sensing cable allows one to provide simultaneous temperature and strain information.

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.

OZ Optics' Foresight™ series of DSTS are BOTDA-based sensor systems. They offer highly accurate and fast measurement of strain and temperature.

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	Foresight™ DSTS
Strain Accuracy	± 1 µstrain	± 30 µstrain	± 2 µstrain
Spatial Resolution	0.1 m	1 m	0.1 m
Length Range	Point sensor	30 km	100 km
Acquisition Time	10s	0-20 minutes	As low as 1 second
Configuration	Many fibers	Single fiber	Loop or single fibers
Temperature Accuracy	± 0.4 °C	N/A	± 0.1 °C
Temperature & Strain	Multiple fibers	Multiple fibers	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 our patent pending special fiber. Like singlemode fiber, the fiber in our cables is used in large quantities for high speed optical telecommunications networks and is 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 distributed strain and temperature sensors through performance enhancement and cost reduction. To get more information on how these technologies may benefit you, please contact us.

Major Applications of Fiber Optic Distributed Strain and Temperature Sensors

Fiber optic distributed strain and temperature 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 distributed strain and temperature sensors involves 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	■	■	■
Crack 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 contact OZ Optics.

Background Articles

Pipeline Buckling Detection:
L. Zou, X. Bao, F. Ravet, and L. Chen, "*Distributed Brillouin fiber sensor for detecting pipeline buckling in an energy pipe under internal pressure*," Applied Optics 45, 3372-3377 (2006).

Pipeline Corrosion Detection:
L. Zou, G. Ferrier, S. Afshar, Q. Yu, L. Chen, and X. Bao, "*Distributed Brillouin scattering sensor for discrimination of wall-thinning defects in steel pipe under internal pressure*," Applied Optics 43, 1583-1588 (2004).

Power Line Monitoring:
L. Zou, X. Bao, Y. Wan and L. Chen, "*Coherent probe-pump-based Brillouin sensor for centimeter-crack detection*," Optics Letters 30, 370-372 (2005).

Crack Detection:
L. Zou and Maria Q. Feng, "*Detection of micrometer crack by Brillouin-scattering-based distributed strain and temperature sensor,*" 19th International Conference on Optical Fiber Sensors, Perth (Australia, 14-18 April 2008).

Accuracy of BOTDA Technology:
L. Zou, X. Bao, S. Yang, L. Chen, and F. Ravet, *"Effect of Brillouin slow light on distributed Brillouin fiber sensors",* Optics Letters 31, 2698-2700 (2006)

Simultaneous Measurement of Strain and Temperature:
L. Zou, X. Bao, S. Afshar V., and L. Chen, *"Dependence of the Brillouin frequency shift on strain and temperature in a photonic crystal fiber",* Optics Letters 29, 1485-1487 (2004)