Fiber Optics Based Strain Measurements

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Fiber Optics has revolutionized telecommunication, and is about to radically change our measurement techniques.

Optical fiber methods of sensing offer many important advantages for engineering use. The optical fibers can be readily installed in a structure (retrospectively if necessary) and produces minimal disturbance of the measurement environment. It is inexpensive, passive and electrically insulating. The range of measurands which is accessible to measurement by optical fiber techniques is very large since the propagation of light within optical fiber is sensitive to a wide variety of physical influences external to it and can easily be detected.

Optical fiber sensors measure environmental conditions such as strain, temperature, magnetic and electrical fields, acoustic waves, and chemical concentrations by determining the induced changes in the intensity, phase, wavelength, polarization, time domain characteristics and modal content caused by such external phenomenon.

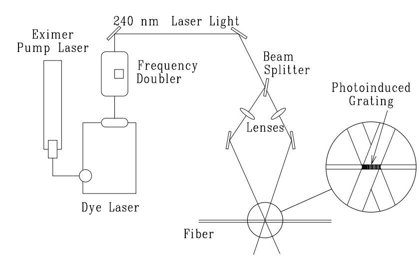
Through extensive preliminary laboratory tests, and more recently the installation of over 50 fibers in a reinforced concrete building, we have identified the ideal type of fiber for installation inside concrete structures, and developed a proper installation procedure which will safeguard the fiber during construction.

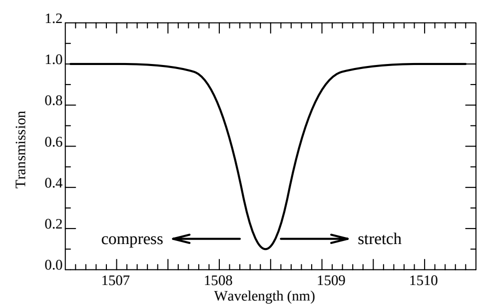
Whereas most current techniques provide an *average* strain along the fiber (interferometric based methods), or a single strain reading (intensity attenuation through fiber microbending) of a single fiber, we are focusing on two different techniques.

Fiber Grating

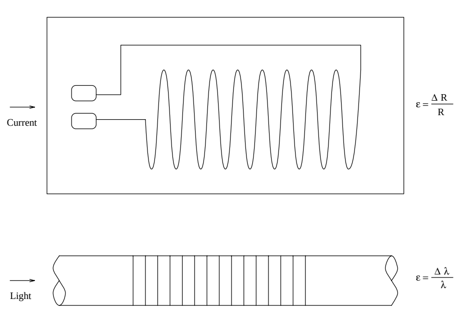
This research/development is conducted with Prof. Anderson, Joint Institute for Laboratory Astrophysics and Department of Physics.

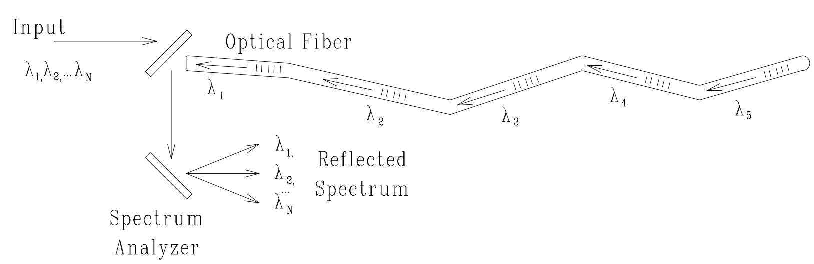
Grating on a fiber are formed using a pulsed ultra-violet source tuned to (or near) 240 nm. Two beams from that source form an interference pattern along a short length of fiber (about 5 mm),





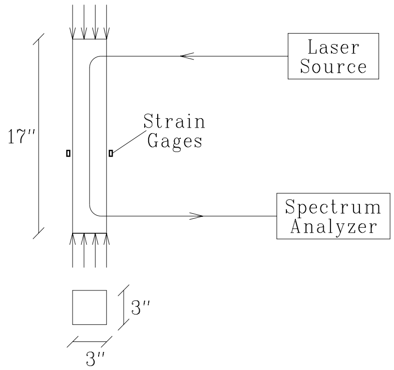
The center wave-length λ which will be affected by the grating is equal to the spacing L between adjacent lines. Hence, strain will be directly obtained from $\varepsilon = \frac{\Delta L}{L} = \frac{\Delta\lambda}{\Lambda}$ and elongation of the optical strain gage will be simply equal to the wavelength shift which can be directly measured. Thus, conceptually there is great similarity between fiber grating strain sensor and foil gage strain gages. However, the former has the big advantage of not only be independent of calibration, but also of providing stable long term measurements without drift.

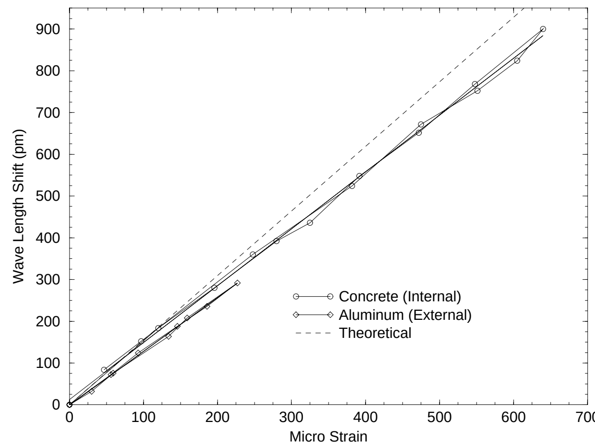




Many gratings, on the order of 100, can be written in a single fiber at desired locations.

For the concrete test, a fiber was embedded inside a prismatic specimen and an electric strain gage mounted on the surface, The specimen was then quasi-statically loaded axially, and strain measurements compared.



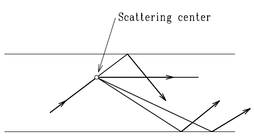


Upon loading, the load, strain and wave length shifts were recorded by a load cell, strain gage, and optical spectrum analyzer respectively. The strain-wave length shift diagram is

OTDR

This research/devlopment is conducted with Prof. Mickelson, Electrical Engineering.

When light is guided by an optical fiber, loss occurs due to Rayleigh scattering which arises as a result of random microscopic variations in the index of refraction of the fiber core.



A fraction of the light that is scattered in a direction 180^o to the propagation axis of the light (backscattered light) is recaptured by the fiber aperture and returned towards the source. By pulsing the input optical signal to a length of fiber, and monitoring the variation in the returned backscattered intensity, spatial variations in the fiber scattering coefficient or cross sections, or attenuation, can be determined.

This forms the basis of optical time domain refractometry (OTDR), which is a well established technique for fault/imperfection location and diagnostic in fiber communications applications. In sensing applications, OTDR can be used to detect localized measurand-induced variations in the loss or scattering coefficient of a continuous sensing fiber. In a basic OTDR measurement, a laser transmitter launches an optical pulse into the fiber under test. The light returned from the fiber by scattering or by reflection back to the OTDR is detected by a photodetector. The time delay between launch and detection is determined by the delay generator. Each value of this time delay, which can be varied by the operator, is uniquely related to a specific location along the fiber. Therefore, distance measurements can be made along the fiber. The waveform of the returned light pulse from the fiber for each time delay is also measured and analyzed. This gives information about fiber properties and features along its length. Important properties and features include insertion and return losses, faults and changes that occur along the fiber.

This technique, still under development, has the potential of providing **continuous strain measurements along the entire fiber**.

Potential Applications

The applications of fiber optics sensors for structural health monitoring are endless: smart structures, automated building construction, crack detection, leakage of hazardous wate containers, monitoring of dams, bridges, offshore structures ...

The new Integrated Teaching and Learning Laboratory of the University of Colorado has over 12 members (beams and columns) instrumented with a total of 50 fibers for stain measurements.

Industrial partnership is being sollicited for the development of the electronic required for each one of those two techniques.