BRIDGE STRUCTURAL HEALTH MONITORING

A COMPARISON OF TECHNOLOGIES

Bridges are vital components of our national transportation and economic infrastructure.

Structural health monitoring data inform the maintenance decision-making process and help lead to increased safety and bridge life expectancy.

Structural health monitoring systems (SHMS) are increasingly specified in the contractual requirements for major bridge construction projects.

Electrically-based and optically-based SHMS options are available … and there are differences in their capabilities, complexity of installation and resultant cost.

SHMS capabilities should be compared when choosing a monitoring solution.

Electrically-based and optically-based systems can measure the same physical parameters on a bridge, but their operating principles are fundamentally different.

Electrically-based

Electrically-based sensing is founded on the measurement of an electrical property (e.g., voltage or resistance) in a sensor element that is a function of the temperature or physical strain at that sensor element. If the temperature or physical strain changes, the electrical property exhibited by the sensor element will change slightly. Copper wires carry this electrical property (e.g., the "signal") to a data acquisition unit (which also is the power source for resistance measurements), where it is converted into a calibrated value of the physical parameter. Examples of electrically-based sensors include resistance element strain gauges and load cells, vibrating wire strain gauges and displacement transducers, piezoelectric accelerometers, and thermocouples.

Wire leads to sensors can act as antennas, and lengths as short as a few tens of meters may pick up electrical noise that causes measurement errors. Longer lines can be especially problematic unless they are thoroughly shielded; metal conduits commonly are required. Even with shielding, the resistance of longer leads may result in desensitizing of a gauge. Any changes in lead wire resistance (such as due to temperature or gradual corrosion) also may be indistinguishable from resistance changes in the gauge itself. Booster amplifiers located near gauges can be added to mitigate some of these effects, but such amplifiers also require power lines in conduit chases.

In an electrically-based system, each sensor must be individually wired to monitoring equipment; multiplexing of several sensors on one line is generally not possible. Installation of a system with many sensors, each with individually shielded lines in conduits (and amplifiers if required), thus can be logistically complicated and costly.

Optically-based

Optically-based sensing is founded on the measurement of the wavelength (color) of light that is reflected by a microscopic grid-like pattern, called a fiber Bragg grating (FBG), embedded in a short section of a longer optical fiber. The fiber is made of glass, which is slightly elastic. The FBG is the sensing element, and the slightest physical distortion or change in temperature at the FBG will cause a shift in the wavelength it reflects. An optical interrogator feeds light spanning a broad spectrum into the optical fiber, measures the wavelength(s) of light reflected back by the FBG(s) along the same fiber, and converts wavelength(s) into calibrated values of the physical parameter. Examples of optically-based sensors include strain gauges, load cells, displacement sensors, accelerometers and temperature sensors.

Optical fiber is nonconductive and is immune to electrical interference, corrosion and the effects of lightning; shielding of sensors and use of conduit for interconnecting fiber are not required. Strain or temperature at a sensor is encoded as the wavelength of light reflected by the FBG, rather than an intensity value, so there is no desensitization of a gauge even if it is located kilometers distant from the monitoring equipment; amplifiers (and power) thus are not required near sensors. Changes in temperature along the interconnecting fiber have no effect on sensing.

During their manufacture, FBGs are tuned to reflect at individually different wavelengths. Apart from the wavelength it reflects, each FBG permits all other wavelengths to pass through on the fiber. This feature enables many FBGs to be multiplexed on one fiber, with each FBG remaining a separately addressable sensor; the logistics of an installation thus are simplified, and overall costs are reduced.

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System sensing methods and properties summarized ...

		Electrically-based sensing	Optically-based sensing
Parameter and sensing method	Strain	Gauge electrical resistance in Wheatstone bridge circuit	Wavelength of light reflected by FBG as a function of tension on FBG
		Frequency of vibrating wire as a function of tension on wire	
	Load	Gauge electrical resistance in Wheatstone bridge circuit	
		Frequency of vibrating wire as a function of tension on wire	
	Displacement	Frequency of vibrating wire as a function of tension on wire	
	Acceleration	Electrical potential generated by physical distortion of piezo-electric element	
	Temperature	Electrical potential generated by thermocouple junction (Seebeck effect)	Wavelength of light reflected by FBG as a function of expansion or contraction of FBG
Multiplexing capability		No - each sensor must be wired separately to data acquisition equipment	Yes – individual FBGs are tuned to different wavelengths, allowing dozens to be connected on a single optical fiber leading to interrogator
Loss in interconnecting line		Loss can become significant beyond a few tens of meters	Loss is insignificant to 25+ kilometers
Effect of interconnecting line length on signal		Length of copper lines has direct impact on the integrity of analog signal from sensor. (A powered amplifier can be located near sensor to boost signal.)	Provided peak wavelength is above the noise floor, any shift in reflected peak wavelength will be detected regardless of the length of the interconnecting fiber
Cable shielding or conduits		Required	Not required
Susceptible to EMI		Yes - copper wires can act as antennas and must be shielded	Immune - nonconductive optical fibers require no shielding
Susceptible to lightning		Yes	No
Electricity at sensor		Yes	No
Safety		Sensors are possible ignition source	Sensors are intrinsically safe
Corrosion effects		Connecting copper wires and junctions must be protected, or parasitic resistance due to any gradual corrosion effects will introduce measurement errors	FBGs and connecting optical fibers are made of glass, immune to corrosion
Sensor lifetime		Typically less than 10 years	Typically 20+ years

Optically-based systems offer many advantages over electrically-based systems!

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FiberStrike optically-based systems from Cleveland Electric Laboratories have a proven record of performance and reliability on multiple major bridges.

Continuous monitoring systems

- Sensor data continuously transmitted to monitoring facility, analyzed in real time
- Well-suited to larger bridges on critical corridors or major routes

Periodic monitoring systems

- Sensor data collected during on-site bridge inspections, subsequently analyzed
- An economical but effective solution for smaller bridges

All Fiber*Strike* SHMS data are presented via IntelliOptics™ software - a powerful but intuitive graphic user interface

- Cohesive architecture facilitates integration and correlation of data from all sensors
- Supports multiple bridges - secure databases, with flexible and tailorable data presentation formats
- Cloud hosting option facilitates remote, simultaneous access by multiple users

Cleveland Electric Laboratories offers state-of-the-art structural health monitoring solutions for new or existing bridges of any size and type, and invites your inquiry.

FiberStrike® by Cleveland Electric Labs
LIGHT CAPTURING MOTION

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