CLEVELAND ELECTRIC LABORATORIES
Fiber Optic Sensing Solutions

FiberStrike™ by Cleveland Electric Labs
LIGHT CAPTURING MOTION

COMMONWEALTH OF PENNSYLVANIA

VETERANS AFFAIRS AND EMERGENCY PREPAREDNESS COMMITTEE HEARING

STATE CAPITOL
HARRISBURG, PA

NORTH OFFICE
HEARING ROOM 1
NOVEMBER 16TH, 2016

PRESENTATION ON EMERGENCY PREPAREDNESS AND RESPONSE MEASURES FOR NATURAL GAS/PETROLEUM PIPELINE INFRASTRUCTURE ACROSS PENNSYLVANIA

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On behalf of Cleveland Electric Laboratories, Inc (CEL), I would like to thank you for allowing me the opportunity to present testimony in regards to the emergency preparedness & response measures for natural gas/petroleum pipeline infrastructure across PA.

CEL is a ninety-six-year-old family owned company. Beginning with thermocouple sensors, CEL has developed into the number one sensing company in America with well-known customers as Honeywell, Boeing, GE, Pratt Whitney, and Rolls Royce, to name a few. Over the past twelve years we have researched, developed and patented fiber optic products that are utilized today for structural health monitoring, security and gas & oil leak detection.

Living on a dairy farm in Rural Valley, PA, for a large part of my life, has given me first-hand experience into what can happen when a gas leak is not detected. The neighboring farm had a leak they did not know about and after time it exploded and the explosion was felt for miles. I consider it an honor to be able to contribute to Pennsylvania finding solutions for the concerns of protecting its citizens and natural resources from catastrophic pipeline failure events, vandalism, theft, injury or loss of life.

All one has to do is type into a search engine, "gas leaks in PA," and a plethora of unfortunate accidents, thefts, vandalisms, and deaths will start to populate your screen. The Trib reported in its' findings that, "Pennsylvania averaged one natural gas leak for every three miles of distribution pipe last year, making the Keystone State's one of the leakiest systems. One in five miles of Pennsylvania pipeline — nearly twice the national average — is older than 1960, federal data show. During the past 10 years, gas explosions killed 10 people and injured 21 in the state."

As recently as April 29th, 2016 a gas line exploded near a man's home in western PA and per NPR news, "The explosion, which occurred on a 30-inch interstate natural gas pipeline, burned one person and caused flames to shoot above nearby treetops in the largely rural Salem Township, about 30 miles east of Pittsburgh. It prompted authorities to evacuate homes and businesses nearby." We have all read, seen or know someone with a story like this and it is commendable that you are taking up the cause to get in front of this issue.

My family, like many others, has been blessed by the benefits of Pennsylvania's vibrant gas business and the goal for all of us is to help secure this critical infrastructure and keep accidents as mentioned above from happening in the future. According to Triblive, ""Accidents involving gas distribution lines have killed more than 120 people, injured more than 500 others and caused more than $775 million in damage since 2004, according to a Tribune-Review analysis of U.S. Pipeline and Hazardous Materials Safety Administration records." One life is too many, and the loss of revenue has been devastating to the economy and has caused many issues for small towns and cities. I owned a small business in Indiana, PA and saw first-hand how the loss of revenue from the gas industry can affect a community, but I have also seen when the gas industry is at its fullest capacity the positive effects it can have as well. I desire to see the robustness from the gas industry and with it, safer and more reliable systems to protect our infrastructure and detect leaks to protect your constituents and the environment.

CEL believes two of the best means of protecting the people of Pennsylvania, the environment and our gas infrastructure is to utilize the best technology for leak detection and the best physical security products available. The initial investment is minimal compared to financial loss from leaks and explosions, and there is no cost that can be attributed to losing a human life.

There are a few options on the market today that are considered more modern, but only a continuously monitored situation is the best. Drones, for example, are great for going in after a leak to see if there is danger and gather intelligence prior to sending in a team, but they are not good for a standard leak detection system. They must be manned and only see the area they are in at the time. They do not continuously monitor the line. What happens if the leak happens after the drone is gone? Just recently they were testing drones for bridge inspection in Ohio and the same issues arose, as they only see what is there at the time. During the test one of the operators crashed a drone, costing the company $35,000.00. The cost for human error can be expensive, whether by accident or purposeful. As of recently, they are finding that individuals will try to shoot the drones out of the air, not to mention that birds have been known to attack as well, causing thousands in damage. Drones are great for entering and collecting intelligence, but not for actual continual detection.

Electrical systems are not suitable as they have spark issues and could cause more harm than good if a leak occurs. They must rely on power that is not always available in remote areas and they ultimately would have issues with ionizing the gas lines where they have to attach with copper grounding.

Fiber optics is the best solution for continuous monitoring, and we believe our FiberStrike system is the most accurate and best solution available. Fiber optics are EMI and EMP resistant, don't have spark issues and will not deteriorate in harsh environments. Fiber optic sensors do not use electricity at the sensors, eliminating any spark issues.

FiberStrike - An advanced fiber optically-based sensing platform that is flexible and scalable, facilitating system configuration for virtually any application. All FiberStrike sensors are passive, have no electronic components, emit no signals and require no electrical power. Sensors are immune to electrical interference and degradation due to chemicals or environmental factors.

FiberStrike systems are available in two different application families, Discrete Sensor Systems and Intrusion Detection Systems, which can be seamlessly deployed together to maximize monitoring and protection of assets:

<u>Discrete Sensor Systems (DSS)</u>

DSS is for specific perimeters and locations. Sensor types include strain gauges, accelerometers, bolt tension (Brainy Bolts), position, acoustic signature, access/interlock switches, air flow and temperature sensors.

Discrete sensors are proven effective for monitoring structural health on multiple civil structures world-wide. The sensors are extremely sensitive, can measure movements down to 10^{-12} m. As many as 50 sensors may be multiplexed on a single optical fiber, facilitating ease of installation, egress routing and data management. Events for hundreds of discrete sensors may be monitored and reported using a single interrogator. The properties of fiber optics allow DSS to be deployed over wide areas or long distances.

Intrusion Detection Systems (IDS)

IDS determines the location of attempted physical intrusions in data communication conduits or trays, thereby helping ensure information security. IDS also may be directly buried, providing the capability to determine location of pedestrian and vehicle traffic intrusion events over distances of kilometers. Intrusion event location accuracy is approximately equal to $\frac{\text{fiber optic loop length}}{100}$ for a single fiber.

This accuracy applies to both communication conduit and direct burial systems. Accuracy improves with the use of multiple co-located fiber loops, making false alarms virtually eliminated by CEL's embedded, advanced designs and configurations.

Key Features of both DSS and IDS FiberStrike systems

The response time to an event is <3 seconds, with an average response time of 1.5 seconds. Event alert systems and data logging are integral components of Cleveland Electric Laboratories' available Command and Control solution. Advanced API provides a .net event output, allowing easy integration with existing C2 or C3 systems. FiberStrike system flexibility facilitates integrating any combination of DSS and IDS into a single head-end.

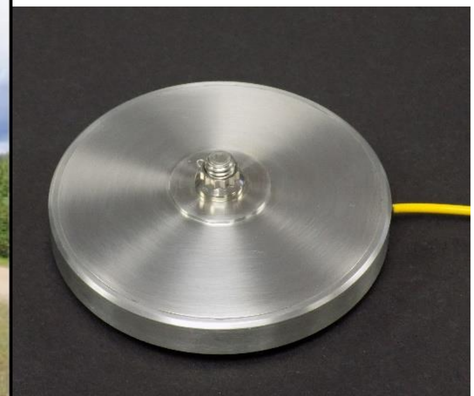
Emergency Management for Leak Detection

One of the bigger objections is cost to retrofit pipe already in the ground, especially in remote areas. First, our product only needs a shallow trench to lay a heavily protected fiber optic cable and then attach an acoustic sensor to the pipe in very select locations, up to half a mile apart from each other. We just use a strap that causes no structural integrity loss to the pipe and none of the materials will make an ionized reaction.

Second, there is a way to make income off the fiber optic lines that would need to be run beside the gas lines. There are many small towns that must still use dial-up internet or DSL at best, making it very difficult for students, employees working from home and those who must access the internet for a variety of reasons (health, reports, emails, etc.). The fiber optic cable run can be used not only for our acoustic system, but it can also be used to allow your constituents to receive high-speed internet and cable access. In the areas with still no high-speed internet, the gas companies would be helping to provide this needed service. They could partner with the cable and/or internet providers to help cover the cost of having the cable run through these areas. It becomes a win-win for everyone. Pipes are safer and secured, and smaller towns gain access to services that were believed to not be available in any foreseen future, and the providers make new streams of income by providing services to new customers.

Last, these sensors, and any other sensors from our product line can all be tied together to give a very robust solution for Emergency Services. If our pipeline, security and structural monitoring sensors were all tied together, you would be very well informed during an emergency. If there were an unfortunate accident, then you would have information from bridges, pipelines, and security, all giving you information for responding to the situation. It would tell you where the event was, if bridges, manholes, mines or gas lines were damaged, which routes would be the best solutions for evacuations. Guess work is no longer an issue. This ties in with IoT (Internet of Things) and being able to obtain information from multiple sources to make the best-informed decision as it pertains to the safety of PA constituents.

We believe that running these fiber optic lines can turn into an income based solution instead of a financial expense that can benefit many in the state of Pennsylvania. This will help move PA onto a path of becoming one of the leaders in the technology age.



We would recommend our acoustic leak detection solution and Brainy Bolt for continuous gas line monitoring that will give you leak indications within three seconds of the event.

The acoustic signatures, across a spectrum, of leak events on a pipeline are captured using FiberStrike ® technology. Our system continuously monitors the acoustic signatures of pipelines, and each pipeline will exhibit an acoustic characteristic. This signature characteristic will change if an anomaly occurs, as a leak, impact, or digging nearby takes place. The FiberStrike system will obtain immediate information, less than three seconds and give the location of the anomaly, as a backhoe, gunshot (even if pipe is not punctured) or leak.

The BrainyBolt® is a powerful tool for remote monitoring of structural health, and is a sensitive measurement fastener (bolt) strain or load. Simultaneous measurement of temperature at fastener, where each sensor is individually calibrated can be detected instantly.

The Brainy Bolt would be utilized where pipes come into pumping stations or wherever a flange needs monitored for temperature, strain or load on that particular junction. These junctions can account for millions a day at some locations, making a great need for them to stay active. They can be tied into the same fiber optic system as our acoustic sensors, and giving a seamless read on the pipelines system health.

Utilizing FiberStrike leak detection and the Brainy Bolt will give gas line owners and citizens ease of mind that if anything starts to occur, the pipeline management team will be notified within seconds of the event and within 10 meters of the incident. You can also combine these with any of our FiberStrike sensors (see appendix for other sensors available). Guess work is gone!

The FiberStrike system is more cost effective than utilizing drones as the sensors will last for over 10 years, and requires nobody going to the physical location unless an event occurs. Other systems still require someone still actively also walking or being in proximity of the gas line. This creates a payback on the system by saving manpower and systems that require electric or gas to utilize.

Securing Gas Pumping Stations, Separating Stations, Processing Plants and Main Line Sales

"Zinchini is accused of tapping into a 3-inch service line that previously fed gas to the Vandergrift Golf Course on Community Park Drive. A "T" connection sent gas to an above-ground manifold operated by Winfall, according to a police criminal complaint."

Hot tapping illegally is another issue that can cost the gas and oil companies hundreds of thousands of dollars, if not millions. FiberStrike Acoustic Sensors can catch this activity on the gas lines and our security products can keep them from coming into field stations to try to tap in by other means, let alone trying to steal anything they can take. There is also the consideration of vandalism or protestors trying to turn off the main valves so gas cannot move. "A group calling itself "Climate Direct Action" reported online that the actions were taken early Tuesday against Enbridge lines 4 and 67 near Leonard, Minn.; the TransCanada's Keystone pipeline in Walhalla, N.D.; Spectra Energy's Express pipeline in Coal Banks Landing, Mont.; and Kinder-Morgan's Trans-Mountain pipeline at Anacortes, Wash."

The Security industry has made amazing advancements over the past decade, but with every detection solution used today there is still vulnerability to periodic failure due to real world problems that cannot be controlled – namely weather conditions, detection devise visibility, and electro-magnetic interference. Each of our products is completely passive, immune to weather effects and undetectable to would-be intruders. FiberStrike security sensors are also EMP (electromagnetic pulse) resistant and will notify of breach within 3 seconds of event.

Keeping people out of areas that are not only dangerous, but where a great loss of revenue can happen quickly if something is disruptive, is also a key aspect of emergency management. The sooner you know an event has occurred the sooner officials can react, and the quicker the gas companies can turn gas lines back on and start generating income that serves as providing tax dollars to the government and income to PA constituents. Our solutions are the "missing link" for nearly every security package.

CEL has developed the FiberStrike family of products that address a host of common weaknesses for the two primary areas of Security; the Protected Distribution System (PDS), and the Intrusion Detection System (IDS).

The purpose of a PDS is to deter, detect and/or make difficult physical access to the fiber optic communication lines carrying national security information. Approval authority, standards, and guidance for the design, installation, and maintenance for PDS systems are regulated by Government Publication NSTISSI 7003 to U.S. government departments and agencies and their contractors and vendors. That publication describes the requirements for all PDS installations within the U.S. and for low and medium threat locations outside the U.S. PDS is commonly used to protect SIPRNet and JWICS networks. Three of our CEL security products that meet these requirements (Conduit Monitoring, Manhole Intrusion Detection and Handhold Intrusion Detection), unveil a significant technological advancement for protecting our Nation's most secret networks.

Intrusion Detection Systems (IDS) are primarily focused on identifying possible incidents, logging information about them, and reporting attempts. In addition, organizations use IDS for other purposes, such as documenting existing threats, and deterring individuals from violating security policies. IDS has become a necessary addition to the security infrastructure of nearly every organization, and our other three security products (Direct Burial Perimeter Detection, Fiber Mats and Fiber Platforms) fit very well with their needs.

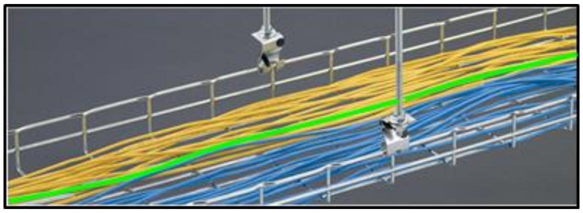
It is important to note that our six security solutions utilize two very different combinations of sensors, fiber, and hardware, but if required, all six systems can be controlled, simultaneously, by our proprietary front-end software.

FiberStrike discrete and distributed sensing products may be combined and integrated as required for creating a comprehensive monitoring system. Our advanced embedded designs and complete scalability allow great flexibility in configurations, and all configurations may be managed from a single head-end control system. The FiberStrike advanced design platform allows virtually limitless system configurations to effectively address a broad range of security applications.

Our two primary security products, Conduit Monitoring and Direct Burial Perimeter Security, use what is called Distributed Sensing, which means that the entire strand of fiber becomes a sensor that can be divided into detection zones of varying lengths through software programming.

Our Direct Burial Perimeter Intrusion Detection system has a wide variety of applications and is primarily designed to warn or alert security forces that an unauthorized intruder is attempting to breach a fence, wall or building. CEL's distributed fiber is buried at a shallow depth, invisible to would-be intruders, and can accurately sense to within a very narrow range one or multiple targets. The fiber can detect vehicular and pedestrian traffic, and provides information on location anywhere along the fiber path. Our fiber's main use is to provide a "first alert" that can direct camera and radar technologies to the point of intrusion for tracking and recording the event.

CEL's Perimeter Intrusion detection technology provides very tight detection zone control over long distances. From the border between two nations, to military and government bases, and industrial facilities such as power, gas and chemical plants, we can protect anything with a high level of accuracy. Our system is “tuned” to recognize real-world conditions such as differing soil compositions and seasonal weather conditions to create a signal pattern that indicates a “normal operating condition.” It can be said that our software “learns” to accept gradual changes to the normal operational environment, but still instantaneously reacts to sudden changes.



The CEL Conduit Intrusion Monitoring solution was created to address the critical need for protecting a wide array of Secret and Top Secret communications networks that are used by our government, military and international security agencies.

There is a critical need for effective Conduit Monitoring in a wide array of Secret and Top Secret communications networks throughout our government, our military, and war zones around the world. By adding CEL distributed sensing fiber to the conduit and cable tray infrastructure the client can instantly recognize, locate and respond to any system tampering.

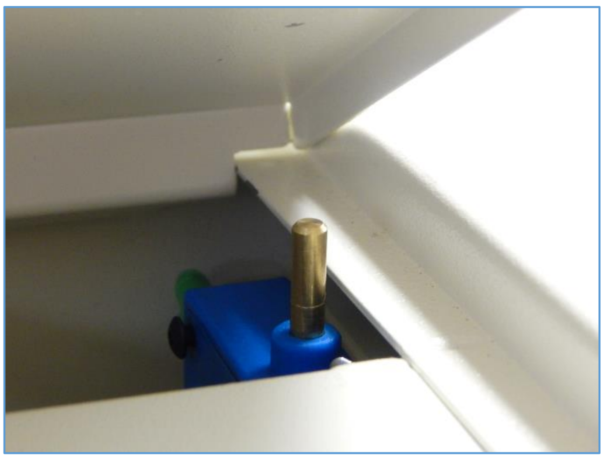
When we talk about Conduit we are referring to fiber optic Communications Conduit, which is usually EMT pipe or flexible molded conduit of various diameters that may be buried, wall mounted or placed in cable trays that are frequently located under or between floors. In military zones there can be dozens of large diameter EMT pipes buried over fifteen feet deep, containing hundreds of critical data fibers. And in many of those applications the pipes are then fully encased in several yards of concrete.

These conduits, like the tributaries of rivers, go in many directions and have frequent terminations in locations such as Command-and-Control Centers, underground Vaults, and massive junction boxes (called Handholds) that carry the critical data to many buildings and command posts.

Our specially manufactured, sensitive fiber is either pulled or blown through conduit along-side the telecommunications fiber that is transmitting secret and top secret data. The sensitive fiber is then “tuned” to recognize and report a suspected intrusion to within one meter of accuracy for instant response. Our solution will virtually always detect the intrusion as soon as something encounters the Conduit, and will alarm without fail if someone actually touches the sensitive fiber.

Our other four security products (Manhole Intrusion Detection, Handhold Intrusion Detection, Fiber Mats and Fiber Platforms) use what we call Point Detection Sensing. These technologies use fiber optic sensors to ascertain exact points of intrusion and a non-sensitive fiber is used to relay the intrusion address back to the front-end software.

FiberStrike Switches provide open/closed status of specific controlled access points such as doors, hatches, manhole covers, floor sections, etc. Being passive, they cannot be electrically bypassed, and they have a rugged, corrosion-resistance packaging available in virtually any configuration.



CEL's advanced API provides a .net event output, easily integrates with other existing Command and Control systems. The API Monitors and provides alerts, location information and data logging when distributed or discrete sensing systems are triggered or disturbed, and the system can be remotely accessible from anywhere in the world. CEL offers the ICS SMS Enterprise™ C3I Command and Control solution including customized graphic user interface that is intuitive and easy to use. We have both commercial and government certified software available for FiberStrike Security Sensors.

Proprietary Software

IntelliOptics™ structural health monitoring software, offered by Cleveland Electric Laboratories, is a powerful, user-friendly interface that collects data from multiple sensor types and displays status information via one centralized program. The software provides a template that may be flexibly tailored for virtually any type of bridge configuration and customized by the user to suit their particular application; the software also easily accommodates future changes, upgrades or additions to sensor systems or configurations. Readings from all sensors are available in real-time, presented in both an intuitive graphic form that is easily understood, and in numeric/tabular format; all data is stored to a secure database, with various options for sensor data backup and retrieval available. IntelliOptics™ may be securely accessed by multiple users from remote locations, with varying levels of user access privileges that are configurable by system administration personnel.

Cleveland Electric Laboratories' FiberStrike ® technology will provide Pennsylvania with the latest technology to secure infrastructure, notify of leaks and help with emergency planning in the unfortunate event of an accident, explosion or disaster. Utilizing our systems will place Pennsylvania on the cutting edge of the most advanced technologies on the markets today.

APPENDIX

http://www.phmsa.dot.gov/pv_obj_cache/pv_obj_id_4A77C7A89CAA18E285898295888E3DB9C5924400/filename/Leak%20Detection%20Study.pdf

http://www.pressconnects.com/story/news/local/pennsylvania/2016/09/14/firm-fast-corrosion-led-pa-pipeline-blast/90365728/

http://triblive.com/news/editorspicks/6772021-74/gas-pipe-explosion

http://fuelfix.com/blog/2014/09/24/pennsylvania-natural-gas-leaks-among-worst-in-nation/

https://insideclimatenews.org/carbon-copy/20140710/methane-may-leak-40-gas-wells-parts-pennsylvania

http://bients.com/pennsylvania-pipelines-bursts-leaks-55000-gallons-gas-one-us-endangered-rivers/

http://paenvironmentdaily.blogspot.com/2016/09/oil-gas-industry-focuses-on-need-for.html

https://stateimpact.npr.org/pennsylvania/2016/04/29/1-injured-after-gas-pipeline-explosion-in-western-pa/

http://powersource.post-gazette.com/powersource/companies/2016/05/04/Corrosion-found-on-Spectra-Texas-Eastern-natural-gas-pipeline-that-exploded-Pennsylvania-Marcellus/stories/201605040191

http://wnep.com/2015/06/10/gas-pipeline-rupture-not-an-explosion/

http://triblive.com/news/editorspicks/6772021-74/gas-pipe-explosion

http://triblive.com/neighborhoods/yourallekiskivalley/yourallekiskivalleymore/8352663-74/gas-peoples-allegheny

http://www.cbc.ca/news/business/pipeline-cutoff-protest-1.3800926

http://www.shutitdown.today/donate_today?splash=1

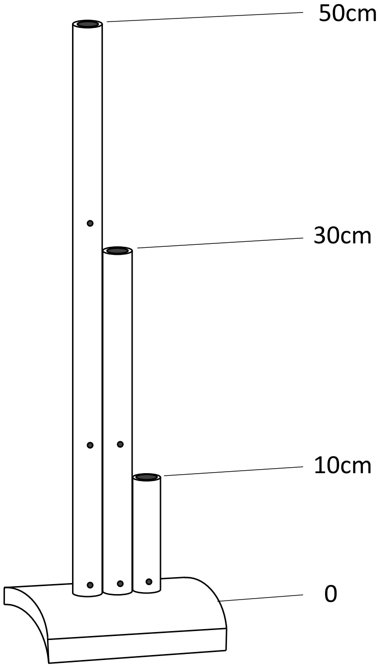
http://www.spe.org/jpt/downloads/

https://www.bsee.gov/

http://ct-strategies.com/wp-content/uploads/2016/02/CT_STRATEGIES_FY16_CBP_Appropriations.pdf

Pipeline leak detection system sensitivity to impact events

Introduction: On 03 June 2016 we performed a brief experiment to assess the sensitivity of our pipeline leak detection (PLD) system to impact events. We used a custom fixture to drop small ball bearings of various known masses vertically onto the top of our experimental pipeline from different known heights. The fixture is illustrated below. Using basic physics, we could calculate the approximate impact force on the experimental pipeline wall caused by the various known masses and drop distances of the ball bearings. By placing the drop fixture at various locations along the pipeline while operating the PLD system, and watching the triggered event capture screen while dropping ball bearings down the vertical guides, we could assess the sensitivity of the PLD to various known impact levels.



Setup: The drop fixture was constructed of PVC. It consisted of three pipes (vertical guides) extending from a saddle designed to rest on the top of the experimental pipeline. The PVC pipes were cut to give drop distances of 10cm, 30cm and 50cm respectively from the top of the pipe to the wall of the steel experimental pipeline when the fixture was placed on top of the experimental pipeline. Vent holes were drilled at intervals in the PVC pipes to avoid air compression effects on the larger ball bearings as they dropped down the pipes.

We used ball bearings as drop objects because they are spherical, it doesn't matter if they tumble as they drop because they are symmetrical, and so they are least affected by variable atmospheric drag effects as they drop. Ball bearings were hardened, so they did not permanently deform (but they did elastically deform) when they impacted the steel test pipeline wall. This is both good and bad when it comes to this sort of experiment, as explained below.

The test was performed with the pipeline static, e.g., no water flowing. The triggered event capture screen in the LabView GUI was utilized, and the LabView routines were typical of those used to date.

Results: We discovered that the sensitivity of the PLD system to impact events, with the setup configuration described above, probably could be summed up in one word: exquisite. We started with larger ball bearings dropped adjacent to a sensor, and it immediately was clear that the PLD could detect much more subtle impacts. We ended up with the drop fixture next to valve 2, placing the impacts 25 feet from sensor 2 and 75 feet from sensor 1, and collected data using the smallest ball bearings available dropped from the shortest possible distances. Even with a tiny ball bearing smaller than a BB, having a mass of only 130 milligrams and dropping a distance of only 10 centimeters, sensor 2 at a distance of 25 feet easily and repeatedly detected the initial impact and subsequent weaker second and even weaker third bounces. Even from 75 feet distance, sensor 1 also reliably detected this initial impact. To put this somewhat in context, the tracking force at the stylus end of a tonearm on a fine turntable (for those people who still like to listen to music on LPs) is commonly 1.25 to 1.5 grams; this is 10X greater than the mass of the tiny ball bearing we dropped 10cm and easily detected. Based on these results, we estimate the PLD demonstrated detection of impacts around the 1 Newton range.

Discussion: The 130 milligram ball bearings were the smallest we had in stock, and 10 centimeters was about the shortest practical drop height in terms of repeatability. When dealing with a mass this small and a drop distance this short, small variations make big differences in the results, and it is difficult to calculate the exact number of Newtons force in an impact. The impact force due to a falling object is calculated as

$$F = \frac{m \cdot g \cdot h}{s}$$

where F = impact force for a falling object, in Newtons
m = mass of the falling object, in kilograms
g = acceleration due to gravity = 9.8 meters/second^2
h = falling height, in meters
s = deceleration distance, in meters

The denominator in the equation above is important. In an ideal experiment the dropped ball bearing would "bury" itself a precisely known and measurable distance into the pipeline as it decelerates and would come to a stop without bouncing; all of the energy in the falling ball bearing would be transferred into the pipeline wall in a single smooth motion. The test pipeline is made of ordinary A36/1018 type steel, and in reality the tiny ball bearings had such low mass that they did not bury themselves into the pipeline steel to any practically measureable degree. Also, as stated earlier, they were hardened, so they elastically deformed but did not permanently deform ... so they bounced a couple times. But if we were to assume a 130 milligram ball bearing dropped from 10 centimeters "buried" itself into the surface of the pipeline 10 microns upon impact and did not bounce, this would equate to 12.7 Newtons force. If we were to assume the same ball bearing dropped from the same distance "buried" itself only 1 micron upon impact and did not bounce (e.g., it stopped over a shorter distance and thus decelerated more violently), this would equate to 127 Newtons force. The wall of the steel pipeline was unpainted and had rusted slightly; this was wiped away before the drop testing, but the surface was not perfect, so it may have accepted a microscopic indentation slightly greater than that of a perfectly smooth and clean steel surface. In general the shorter "bury" distance and associated higher Newtons force figure seem appropriate. However, in addition to seeing the initial impact and weaker second impact after a bounce, we repeatedly and easily saw the signature (after a second bounce) from the much weaker third impact, and this was with the pipeline transmitting the energy from this tiny third impact to a sensor 25 feet away. The estimated falling height for the third (weakest) impact after the second bounce was only about 1 cm. These data lead us to conclude that we likely can detect impact events in the 1 Newton range, or lower if the impact is closer to the sensor. Larger impacts would be detectable from longer ranges.

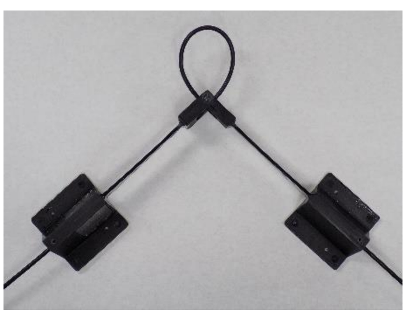
Disclaimer: These numbers are based on the data we collected with the experimental pipeline configuration as it exists here and now. However, this sensitivity seems like a respectable figure.

Other Sensors for Structural Health Monitoring.

Strain Sensors & Temperature Sensors: Measures strain on an object and temperature.

Accelerometers: Measures vibration, shock and motion.

Displacement Sensor: Measures distance and heights.



Crack Sensor: Measure movement of identified crack. Can be done up to a three-axis movement.

Security Platform: Indicates in less than 3 seconds when someone steps on platform.

Fiber*Strike* Applications

Fiber*Strike* Products	Structural Health	Security		Industrial	Aerospace	Mining and Petroleum	
		Discrete	Distributed			Safety	Production
Acoustic Sensor Array			X			X	X
BrainyBolt	X			X	X	X	X
OptiMic	X	X	X	X	X	X	X
Position Switch	X	X		X	X	X	X
Linear Position	X	X		X	X	X	X
Rotary Position		X		X	X	X	X
Pressure	X			X	X	X	X
Temperature	X	X		X	X	X	X
Optical Slip-ring				X	X	X	X
Strain Gauge	X	X		X	X	X	X

The context of this matrix is Fiber*Strike* applications only, not all products designed and/or produced by CEL-ATG.

Fiber*Strike* Applications

Fiber*Strike* applies to all parts of the supply chain:
Raw materials
Material transport/processing
Design & development
Performance monitoring and improvement
Asset and resource protection

The context of this matrix is Fiber*Strike* applications only, not all products designed and/or produced by CEL-ATG.

Security		Mining and Petroleum		Industrial	Structural Health	Aerospace	Fiber*Strike* Products
Distributed	Localized	Production	Safety				
Perimeter Conduit		Processing	Acoustic monitoring				Fiber Acoustic Array
		Equipment	Equipment	Strain	Strain	Strain	BrainyBolt
Acoustic monitoring	Acoustic monitoring	Acoustic norm properties	Acoustic monitor (leak detection)	Acoustic properties	Acoustic signature	Acoustic monitoring	OptiMic
	Access point	Equipment	Access point	Switch position	Events counter	Control state	Binary Position (switch)
	Access point	Equipment	Equipment	Linear position	Movement	Movement	Linear Position
		Equipment	Equipment	Rotary position	Movement	Movement	Rotary Position
		Equipment	Equipment	Pressure	Pressure	Pressure	Pressure
	Body temp monitoring	Processing	Environment and processing	Temperature	Temperature	Temperature	Temperature
		Data, rotating machinery	Contact-less data transmission	Data, rotating machinery	Data, rotating machinery	Data, rotating machinery	Optical Slipring
	Weight or disturbance	Processing	Equipment monitoring	Strain, vibration	Strain, vibration	Strain, vibration	Strain gauge

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Bridge White Paper

Cleveland Electric Laboratories is a family-owned business that has been serving our customers since 1920 by proudly providing top-quality products, excellent customer service and exceptional attention to critical details.

BACKGROUND

Over 600,000 bridges currently exist across the United States. These structures constitute a vital component of our national transportation and economic infrastructure. The average age of these structures is 44 years, and on the basis of periodic inspections, one in nine (over 67,000) have been classified as structurally deficient. Periodic inspections are valuable, but most depend on human observations that may span a few hours or days, and the tools used during such inspections often are limited to binoculars, tape measures, hammers and a chain. As illustrated by the tragic collapse of the I-35 bridge in Minneapolis in 2007, legacy inspection methods can miss problems.

STATEMENT OF NEED

Instrumentation that provides continuous structural performance data over the long term in both current and future bridges is needed to give insights into structural health, to enable timely and appropriate application of maintenance resources to maintain bridge performance, and ultimately to improve the safety, longevity and reliability of such vital infrastructure assets.

SOLUTION

The Advanced Technologies Group of Cleveland Electric Laboratories (CEL) has designed and installed sensing systems to continuously monitor bridge structural health. CEL sensing systems are based on fiber optics and use light to capture motion. CEL's sensors utilize tiny sensing elements known as fiber Bragg gratings (FBGs), which are extremely sensitive and capable of measuring any parameter that can be translated into a slight physical movement. FBG-based sensors have reliability exceeding that of legacy electrically-based sensors, are passive and emit no signals, require no electrical power, are environmentally rugged, and are immune to lightning. They are useful during new construction by enabling continuous monitoring of concrete foundation temperatures and curing, and in the tensioning of steel members; the same sensors subsequently will support permanent long-term bridge monitoring under wind and traffic loads, seismic activity, and/or later disturbances such as barge collisions or nearby construction excavations. In addition to structural monitoring, FBG-based sensors also may be installed in strategic locations on or around bridges for security monitoring purposes. Hundreds of FBG sensors of multiple types may be mixed and matched, all being continuously interrogated over one optical fiber bundle from a remote location which may be dozens of kilometers distant from the bridge if necessary. Such attributes make CEL's sensing systems attractive in comparison to legacy sensing system approaches. Existing unused telecom fiber, if it is of the correct type, may be used to link a bridge with the optical interrogator equipment. The interrogator, which may be installed in an unattended environmental enclosure, is connected via standard Ethernet to a computer located in a monitoring facility. Available system software on that computer provides a single cohesive instrumentation solution that will log and display data from multiple sensor types numerically and/or graphically, in traditional formats with numbers or with intuitive visual icons and alarms overlaid on an image of a bridge at each sensor location. Data or automatically-generated threshold limit alerts provided by the software also may be transmitted in real time to authorized users anywhere in the world via cellphone or internet.

INSTALLATION EXAMPLES

CEL has installed its sensing systems in multiple new and existing bridge structures; a few examples include the Indian River Inlet Bridge (Delaware), the Arsenal Bridge (Rock Island, IL), the I-20 Bridge (Vicksburg, MS), the Chulitna Bridge (Denali National Park, AK) and the Chiapas and Papaloapan Bridges (Mexico). Such sensing systems have proved their value in providing timely and valuable information on bridge structural health. The experiences gained through the diversity of these installations also has led to valuable insights into appropriate features needed to ensure effective structural sensing solutions for virtually any new or existing bridge design.

CONCLUSION

Implementing a continuous monitoring capability that enables knowledge of structural health in bridges is a sound economic investment. From a holistic point of view toward monitoring bridge performance over the long term, CEL experience indicates that the most efficient system configuration is one in which all sensors employ a common operating principle and data format, such that all sensor data is readily accessible via one instrumentation system. Such an architecture facilitates implementation of a common graphic user interface, facilitates real-time correlation of variables between sensors, and can allow predictive analysis that otherwise may be difficult to perform if a variety of sensor systems employing different principles (e.g., a mixture of electrical and optical) is employed. CEL provides such a system architectural approach. Taken a step farther, adopting a particular instrumentation architecture as standard across multiple bridges facilitates interconnectivity to a central monitoring facility that can serve multiple bridges hundreds of miles apart, thereby reducing infrastructure costs; the existing telecommunications fiber infrastructure may also be leveraged to further reduce the cost of implementing a standardized instrumentation architecture reporting to a central location. Of all instrumentation system types, CEL experience has repeatedly demonstrated that optical sensing systems and associated software provide by far the greatest capability and performance.

FBG-based optical sensing may be regarded as the technology of choice for structural health monitoring — especially for bridge monitoring. Cleveland Electric Laboratories can apply their experience and expertise in optical sensing to provide effective solutions that enable long-term holistic structural monitoring of virtually any bridge of the past, present or future.