Distributed Strain and Temperature Sensor

OZ Optics Limited

June 2020
Corporate Background

- Founded in 1985;
- Corporate headquarter located in Ottawa, Canada;
- Manufacturing facility in Ottawa/Canada, Izmir/Turkey and Jiaxing/China;
- Seven Product Groups: Laser-to-Fiber Delivery Systems, High Power Fiber Optic Components, Polarization Maintaining Products, Attenuators, Opto-Electronic Packaging, Fiber Optic Test Equipments, and Fiber Optic Sensor Systems;
- Sales offices in Canada, USA, Europe, Turkey, and China.
Corporate Statements and Quality Policy

Our Vision
- Be the preferred supplier of choice
- Capture and expand market share
- Maximize shareholder value

Our Mission
To become the leading provider of innovative optical products to telecom to non-telecom sectors

Our Core Values
- Leadership
- Teamwork
- Boldness
- Commitments
- Innovation
- Rewards

Our Quality Policy
Provide our Customers with a competitive advantage, leveraging performance, price and delivery, through a continuous process of Quality advancement in all areas of our Company.

Communicate effectively to our Customers, Suppliers and Shareholders our commitment to Quality, continuous improvement and to abide by any applicable requirements.

Promote opportunities of professional development for all members of our company through education, training and personal challenge.
Company Profile

Over 450 employees worldwide:

- **OZ Canada**: 250+ employees
- **OZ China**: 120+ employees
- **OZ Turkey**: 80+ employees
Company Profile

ISO 9001:2015 Certified

Broad Patent Portfolio

Advanced Proprietary Processing Technology
Company Profile

*OZ Optics is lead by an experienced team:*

- Ömür Sezerman, Chairman, President & CEO
  * Founder and CEO since inception (35 years)
- Zahide Sezerman, VP of Human Resources
  * With OZ Optics since inception (35 years)
- Garland Best, VP of Components Division
  * 28 years at OZ Optics
- Gordon Youle, VP of Test Equipment Division
  * 21 years at OZ Optics
- Martin Powell, Operation Manager
  * 16 years at OZ Optics
- Metin Sezerman, General Manager of OZ Turkey
  * 19 years at OZ Optics
- Bing Li, General Manager of OZ Optics China
  * 16 years at OZ Optics
Company Profile

Experienced and well-trained staff in following fields:
- optical, mechanical, electronics & software

- CNC Machine Shop
- Femto-Second Laser Lab
- Clean Room
- Laser Conditioning/Cleaving
- AR Coating
Core Competencies

* Pioneer in Polarization Maintaining (PM) Components
* Leader in Wavelength Flattened, High Power & Low PDL Components
* Leader in High Power Fiber Optic Delivery Systems
* Custom Test Equipment, Including Polarization Test Equipment and FTTH Equipment
* Widest Range in Attenuator Product Offering
* Fiber Optic Distributed Strain and Temperature Sensors
* Complete product line for OCT applications & 2 Micron
* Now available: Bias Controllers, Spectrometers, Optical Noise Generators and Broadband Polarization-Entangled Photon Source,
Leading Technology

Three Product Groups

- Fiber Optic Components, 85%
- Optical Test Equipments, 10%
- Fiber Optic Sensor, 5%

Over 1,000 Products

Leading Edge R&D
Leading Technology

Featured Products
Leading Technology

Featured Products

- Fiber Optic Attenuators for SM, PM, and MM Fibers
- Fiber Optic Components for Optoelectronic Packaging
- Laser & Laser Diode to Fiber Delivery Systems
- Fiber Optic Test Equipment
Industry Standards

All products manufactured are in strict accordance with international industry standards:

- Qualified for F35 JSF and F18 Program
- **Telecordia Compliance**
- **CE Compliance**
- **RoHS Compliance**
- **REACH Compliance**
- **ISO 9001:2015 Certified (Canada, China and Turkey)**
- Controlled Goods Directorate Registered
Marketing Strategy

Application Market:

Using our strong direct sales and distributors, we address the following markets:
By leveraging the technology and expertise gained since its inception, OZ Optics has attracted a broad range of customers in the telecom / datacom, medical, military, security, industrial, construction, aerospace, power utilities, petrochemical and educational sectors.

Marketing Strategy

**Application Market:**

- **Revenue Allocation:**
  - Energy: 5%
  - Medical & Pharmaceutical: 10%
  - Telecom/Datacom: 40%
  - Industrial: 10%
  - Educational: 5%
  - Military & Homeland Security: 30%
### Marketing Strategy

#### Global Sales Network

OZ Optics has resellers and distributors in over 30 Countries & Regions with over 10,000 customers worldwide:

<table>
<thead>
<tr>
<th>Country</th>
<th>Flag</th>
<th>Country</th>
<th>Flag</th>
<th>Country</th>
<th>Flag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>🇦🇹</td>
<td>Denmark</td>
<td>🇩🇰</td>
<td>Italy</td>
<td>🇮🇹</td>
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<tr>
<td>Belgium</td>
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<td>France</td>
<td>🇫🇷</td>
<td>Japan</td>
<td>🇯🇵</td>
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<tr>
<td>Netherlands</td>
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<td>Germany</td>
<td>🇩🇪</td>
<td>Norway</td>
<td>🇳🇴</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>🇧🇪</td>
<td>Greece</td>
<td>🇬🇷</td>
<td>Poland</td>
<td>🇵🇱</td>
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<tr>
<td>Brazil</td>
<td>🇧🇷</td>
<td>Hong Kong</td>
<td>🇭🇰</td>
<td>Portugal</td>
<td>🇵🇹</td>
</tr>
<tr>
<td>Canada</td>
<td>🇨🇦</td>
<td>India</td>
<td>🇮🇳</td>
<td>Singapore</td>
<td>🇸🇬</td>
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<td>China</td>
<td>🇨🇳</td>
<td>Ireland</td>
<td>🇮🇪</td>
<td>South Korea</td>
<td>🇰🇷</td>
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<td>Switzerland</td>
<td>🇨🇭</td>
<td>Sweden</td>
<td>🇸🇪</td>
<td>United States</td>
<td>🇺🇸</td>
</tr>
<tr>
<td>Japan</td>
<td>🇯🇵</td>
<td>Taiwan</td>
<td>🇹🇼</td>
<td>Turkey</td>
<td>🇹🇷</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>🇬🇧</td>
<td>United Kingdom</td>
<td>🇬🇧</td>
<td>Thailand</td>
<td>🇹🇭</td>
</tr>
</tbody>
</table>
Operation Strategy

Manufacturing Strategy

- **Made in Turkey**
- **R&D/Design/Engineering**
- **Customer Qualification**
- **Customer**

- **OZ CND Qualification**
- **Made in China**
- **Sub-Components**
- **Worldwide Sourcing**

- **Made in Turkey**
- **Customer Qualification**

- **OZ Canada**
- **R&D/Design/Engineering**
- **Customer**

- **OZ CND Qualification**
- **Customer**

- **Sub-Components**
Marketing & Operation Strategy

Competitive Advantage

Superior Technology
Innovative Engineering

Exceptional Quality
And Service

Competitive
Pricing

Extensive Experience
In Fiber Optics
Manufacturing

Global
Presence

Success
Branch Network

OZ OPTICS CANADA
(Headquarters)

OZ OPTICS TR
(Turkey Factory)

OZ OPTICS CHINA
(Jiaxing Factory)
Branch Network

Facility - Ottawa Headquarters

- 60,000 sq ft. – Manufacturing and R&D Facilities
- 15,000 sq ft. – Admin, Sales and Marketing
- 15,000 sq ft. - Training and Fitness Facilities
Branch Network

Facility - Ottawa Headquarters

Production Area

Training Centre Building

Meeting Room

Swimming Pool
Branch Network

Facility - Turkey Factory

Izmir, Turkey

- Operational since 2000
- 33,000 sq ft. Manufacturing Facility
- Located in Free Trade Zone
- Low Tax Rates
- Sub Component Parts Manufacturing
- High Quality Labor
Branch Network

Facility - China Factory

Jiaxing, China

- Operational since June 2010
- Wholly Foreign Owned Enterprise
- Cost Effective Manufacturing
- High Quality Labor
- Supply Chain Integration
Branch Network

Facility - China Factory

Jiaxing, China

- Located in Economic Development Zone
- 4000+ sq meters - Total Area
  - 500 sq meters - Admin, Sales and Marketing
  - 3500 sq meters - Manufacturing Area
  - 500 sq meter - Class 10,000 Clean Room
  - 300 sq meter - ESD Working Area
OZ Optics China

Zhejiang OZ Optics Technologies Co., Ltd

- Operational since June 2010
- Wholly Foreign Owned Enterprise
- NPI & Production Line Setup
- On-site Training by OZ CND
- Began Mass Production in September 2010
- Completed Main Facility Expansion in 2019
Conventional Temperature & Strain Sensors

* Temperature sensor: thermocouple
* Strain sensor: electrical strain gauge
  * Temperature influence
  * Electromagnetic interference (EMI)
  * Humidity influence
  * Point sensor
**Fiber Optic Sensors**

* **Advantages of Fiber Optic Sensors**
  * Electrically insulating materials (no electrical cables are required) — high voltage environments
  * Chemically passive, not subject e.g. to corrosion
  * Immune to electromagnetic interference (EMI)
  * Wide operating temperature range

* **Fiber Bragg Grating Sensor**
  * Strain resolution and accuracy: < 2 με
  * Cannot distinguish strain and temperature
  * Point sensor

* **Distributed Fiber Optic Sensors**
  * Raman scattering based — only temperature
  * Brillouin scattering based — both temperature and strain
  * Rayleigh scattering based — DAS, Luna (70m long sensing fiber)
Fiber Optic Sensors

Fiber Bragg Grating Sensor
* Sensor medium: Fiber Bragg grating
* Laser source and data acquisition system: Spectrum analyzer

Distributed Fiber Optic Sensors (Brillouin Sensors)
* Sensor medium: Conventional communication fiber (such as SMF, LEAF, etc..)
* Laser source and data acquisition system: Brillouin sensor system
  * OZ Optics [Foresight™ DSTS (Distributed Strain and Temperature Sensors)]
  * Omnisens (STA)
  * Yokogawa (AQ8603) (Discontinued)
  * Sensornet (DTSS)
  * Neubrex (Neubrescope)
  * fibrisTerre (fTB 2505)
  * febus
Working Principle — BOTDA

\[ \nu_B = \nu_{B_0} + C_T(T - T_0) + C_\varepsilon(\varepsilon - \varepsilon_0) \]

\( T \) and \( e \) are variables
In order to differentiate these two variables, Brillouin peak in the spectrum is required.
**Working Principle — BOTDA**

When the beat frequency matches the intrinsic Brillouin frequency of the fiber $\nu_B$, we will get maximum of Brillouin spectrum.

$\nu_B$ changes linearly with the strain and temperature exerted.

$$\nu_B = \nu_B^0 + C_T (T - T_0) + C_\varepsilon (\varepsilon - \varepsilon_0)$$

Sensor medium: standard telecom optical fiber

Loss
Comparison of BOTDR and BOTDA

BOTDR (Brillouin Optical Time Domain Reflector)

- Probe Laser: $v_0$
- Pulse Modulator: $v_0$ (CW)
- Heterodyne Receiver: $v_B(v'_B)$
- Digital Processor

10^3 photons $v_B(v'_B)$

at most 1 photon $v_0 \pm v_B(v'_B)$

Brillouin scattered light

High dynamic range

Weak signal

BOTDA (Brillouin Optical Time Domain Analyzer)

- Probe Laser: $v_0$ (CW)
- Pulse Modulator: $v_0$
- Heterodyne Receiver: $v_B(v'_B)$
- Digital Processor: $v_0 + v_B(v'_B)$ (CW)

Coherent amplification $v_B(v'_B)$

- Pump Laser: $v_0 + v_B(v'_B)$ (CW)

OZ Optics

shop.ozoptics.com
www.ozoptics.com
3U + Laptop, 4 Channel Model
Foresight™ DSTS

Silver Level Winner

US Patents #: 7499151, 7599047 and 9568307
**Merits of DSTS BOTDA**

* Coherent amplification of Brillouin scattering signal
  ⇒ longest measured range (200 km fiber length)
* Narrowest Brillouin spectrum (~ 45 MHz)
  ⇒ highest resolution of strain and temperature
* Special low loss fiber components and electronic processing
  ⇒ high stability of system
* With proprietary techniques, Brillouin frequency is extracted accurately
  ⇒ highest accuracy in measuring strain and temperature separately or simultaneously
* New technology
  ⇒ quick measurement of strain and temperature (as low as 1 second: 1 Hz)
Merits of DSTS BOTDR

* Low noise detection for weak spontaneous Brillouin scattering signal
  ⇒ long measured range (70 km in one direction)
* Special low loss fiber components and electronic processing
  ⇒ high stability of system
* Sophisticated design
  ⇒ Small size and light weight
## Double End (A) Competitive Analysis

<table>
<thead>
<tr>
<th>Company</th>
<th>OZ Optics</th>
<th>OmniSens</th>
<th>Neubrex</th>
<th>fibrisTerre</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technology</strong></td>
<td>BOTDA</td>
<td>BOTDA</td>
<td>BOTDA</td>
<td>BOFDA</td>
</tr>
<tr>
<td><strong>Maximum Sensing Range</strong></td>
<td>(fiber length up to 200km)</td>
<td>60 km (120km max. total fiber loop distance)</td>
<td>27km</td>
<td>25km</td>
</tr>
<tr>
<td><strong>Channels</strong></td>
<td>Internal 4</td>
<td>Internal 4</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>External 24</td>
<td>up to 20 channels via external SO-N Switch module</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Highest Spatial Resolution / Spatial step (sample interval)</strong></td>
<td>10cm/$\sigma$/5cm</td>
<td>50cm/25cm</td>
<td>2cm/1cm</td>
<td>50cm/5cm</td>
</tr>
<tr>
<td><strong>Dynamic Range at highest spatial resolution</strong></td>
<td>7dB</td>
<td>N/A</td>
<td>0.5dB</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Strain / Temperature Accuracy (Repeatability) ($\sigma$)</strong></td>
<td>2$\mu\varepsilon$/0.1°C (1m spatial resolution / 2km fiber / 1 minute 40 seconds)</td>
<td>2$\mu\varepsilon$/0.1°C (1m spatial resolution / 2km fiber / 10 minutes)</td>
<td>7.5$\mu\varepsilon$/0.35°C</td>
<td>2$\mu\varepsilon$/0.1°C</td>
</tr>
<tr>
<td><strong>Strain / Temperature Resolution</strong></td>
<td>0.1$\mu\varepsilon$/0.005°C</td>
<td>2$\mu\varepsilon$/0.1°C</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Specifications of other vendor’s products are based on their public datasheets.

1) Based on scientific definition, the spatial resolution is defined by pulse width. 10ns pulse width is equivalent to 1m spatial resolution while 1ns pulse width is equivalent to 0.1m spatial resolution.
## Single End (R) Competitive Analysis

<table>
<thead>
<tr>
<th>Company</th>
<th>OZ Optics</th>
<th>OmniSens</th>
<th>Neubrex</th>
<th>Febus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>BOTDR</td>
<td>BOTDR</td>
<td>BOTDR</td>
<td>BOTDR</td>
</tr>
<tr>
<td>Channels</td>
<td>Internal 4 External 24 More channels optional</td>
<td>Internal 4 up to 20 channels via external SO-N Switch module</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Maximum Sensing Range</td>
<td>70km (max 100km)</td>
<td>45km</td>
<td>27km</td>
<td>30km (max 100km)</td>
</tr>
<tr>
<td>Highest Spatial Resolution / Spatial step (sample interval)</td>
<td>1m&lt;sup&gt;1)&lt;/sup&gt;/5cm</td>
<td>1.5m/25cm</td>
<td>0.5m / 5cm</td>
<td>1m</td>
</tr>
<tr>
<td>Dynamic Range at highest spatial resolution</td>
<td>10dB</td>
<td>10dB</td>
<td>2dB</td>
<td>N/A</td>
</tr>
<tr>
<td>Strain / Temperature Accuracy (Repeatability) (σ)</td>
<td>10με/0.5°C</td>
<td>20με/1°C</td>
<td>30με/1.5°C</td>
<td>10με/0.5°C</td>
</tr>
<tr>
<td>Strain / Temperature Resolution</td>
<td>0.1με/0.005°C</td>
<td>2με/0.1°C</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Specifications of other vendor’s products are based on their public datasheets.

1) Based on scientific definition, the spatial resolution is defined by pulse width. 10ns pulse width is equivalent to 1m spatial resolution while 1ns pulse width is equivalent to 0.1m spatial resolution.
## Combo Unit Competitive Analysis

<table>
<thead>
<tr>
<th>Company</th>
<th>OZ Optics</th>
<th>OmniSens</th>
<th>Neubrex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>BOTDA</td>
<td>BOTDR</td>
<td>BOTDA</td>
</tr>
<tr>
<td>Maximum Sensing Range</td>
<td>(fiber length up to 160km)</td>
<td>70km (max 100km)</td>
<td>60 km (120km max. total fiber loop distance)</td>
</tr>
<tr>
<td>Channels</td>
<td>Internal 4 External 24 More channels optional</td>
<td>Internal 4 up to 20 channels via external SO-N Switch module</td>
<td>N/A</td>
</tr>
<tr>
<td>Highest Spatial Resolution / Spatial step (sample interval)</td>
<td>10cm/1/5cm</td>
<td>1m/1/5cm</td>
<td>50cm/25cm</td>
</tr>
<tr>
<td>Dynamic Range at highest spatial resolution</td>
<td>7dB</td>
<td>10dB</td>
<td>N/A</td>
</tr>
<tr>
<td>Strain / Temperature Accuracy (Repeatability) (σ)</td>
<td>2με/0.1°C (1m spatial resolution / 2km fiber / 1 min 40 secs)</td>
<td>10με/ 0.5°C</td>
<td>2με/0.1°C (1m spatial resolution / 2km fiber / 10 mins)</td>
</tr>
<tr>
<td>Strain / Temperature Resolution</td>
<td>0.1με/0.005°C</td>
<td>0.1με/0.005°C</td>
<td>2με/0.1°C</td>
</tr>
</tbody>
</table>

Specifications of other vendor’s products are based on their public datasheets.

1) Based on scientific definition, the spatial resolution is defined by pulse width. 10ns pulse width is equivalent to 1m spatial resolution while 1ns pulse width is equivalent to 0.1m spatial resolution.
Sensing Range -- The Longest Functional Measurement Fiber Length.
Results comparison between OZ unit and other vendor’s unit. Fiber under test is 101km long. Results are displayed below. Same test configurations are applied.

Other Vender

OZ Optics DSTS

Brillouin Center Frequency vs fiber length (full scale)

Brillouin Spectrum at 80km.
Reasonable Spectrum can be only found at 55km.

Brillouin Spectrum at 100.5km.
### Comparison: DSTS BOTDA and Raman based DTS

<table>
<thead>
<tr>
<th></th>
<th>Raman based DTS</th>
<th>OZ Foresight™ DSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Max Fiber Length</strong></td>
<td>20km (MM)</td>
<td>200 km round-trip (physical distance 100 km)</td>
</tr>
<tr>
<td><strong>Fiber Type</strong></td>
<td>Multimode</td>
<td>Standard telecom singlemode</td>
</tr>
<tr>
<td><strong>Response time @ 20km, 2C Resolution</strong></td>
<td>More than 10 minutes</td>
<td>30 seconds to 3 minutes</td>
</tr>
<tr>
<td><strong>Configuration</strong></td>
<td>Single ended or double ended</td>
<td>Single ended or double ended</td>
</tr>
<tr>
<td><strong>Measurement Base and Precision</strong></td>
<td>Intensity based</td>
<td>Frequency based</td>
</tr>
<tr>
<td></td>
<td>Require calibrations</td>
<td>No calibration required after setup</td>
</tr>
<tr>
<td></td>
<td>Sensitive to attenuation changes</td>
<td>Not sensitive to attenuation changes</td>
</tr>
<tr>
<td><strong>Dynamic Range</strong></td>
<td>3-4 dB</td>
<td>25-30 dB</td>
</tr>
<tr>
<td></td>
<td>May fail when attenuation increases</td>
<td>Allows better immunity to attenuation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wider measurement range and longer use of installed fiber</td>
</tr>
<tr>
<td><strong>Measurand</strong></td>
<td>Temperature</td>
<td>Temperature and Strain</td>
</tr>
<tr>
<td><strong>Measurement Resolutions</strong></td>
<td>Comparable @ over 1 minute</td>
<td>Comparable @ several seconds</td>
</tr>
</tbody>
</table>
Competitive Analysis

- Neubrex
- fibrisTerre
- Sensornet
- OZ Optics
- Omnisens

**Feature Highlights:**
- High spatial resolution: 10cm
- High measurement accuracy
- Strain: ± 25 με
- Temperature: ± 1°C
New Features

* New GUI
* Full DLL support
* Auto-recovery from power outage
* Auto Channel Switch allows continuous scans between channels.
New GUI Login

Choose Mode

- B-OTDA
  - STRAIN & TEMPERATURE
  - HIGH RESOLUTION
  - HIGH SPEED
  - BRILLOIN ANALYZER

- B-OTDR
  - LOW RESOLUTION
  - COMBINED
  - STRAIN & TEMPERATURE
  - BRILLOIN REFLECTOMETER

DSTS2 Login

Username: 
Password: 

[Buttons]
- Login
- Register/Reset Password
- Play Video
- Exit
- Help
Database
Measurement Screens
OZ Optics Foresight™ DSTS Benefits

- Reducing risk and influence of failure
  - Fast response
  - Status trend in long term
  - Full range of coverage
- Reducing operating expenses
  - No future re-calibration of unit
  - Expected cable life over 20 years
Applications

- Oil and Gas Pipeline Monitoring
- Dyke and Levee Monitoring
- Power Line Monitoring
- Oil and Gas Well Monitoring
- Bridge and Building Monitoring
- Border Security Monitoring
Oil and Gas

- Pipeline Leakage Monitoring
- Well Integrity Management
- Refinery Temperature Monitoring
Pipeline Leakage Monitoring System

* Policy Requirement
* Economic Requirement

- Leakage
- Liquid Spill
- Ambient Temp Change
- Temperature of sensing cable changes
- Detected

TCP/IP

SCADA

local control room

Temperature Sensing Cable
Third Party Evaluation

- Leakages from a 1/8” orifice with an injection pressure as low as 22 psi, and a temperature difference of 20° F between the soil and line temperatures, have been easily detected and accurately located.
- An impressive leakage detection response time of less than 2 minutes has been achieved.
- Evaluation was done under laboratory conditions over a period of one month, by Southwest Research Institute (SwRI) and funded by major oil companies through a joint industry program.
Performance

Large leakage detection from 1/8” orifice with 400 psi injection pressure, soil temperature before test: 85°F, line temperature: 115°F.

Small leakage detection from 1/8” orifice with 50 psi injection pressure, soil temperature before test: 73°F, line temperature: 90°F.
Soil Temperature Monitoring
Pipeline Corrosion Monitoring

Pipeline corrosion monitoring in Canmet Materials Technology Laboratory, NRCan, Ottawa, NACE International — Corrosion 2008 Conference and Expo, New Orleans (Louisiana, USA 16-20 March, 2008).
Pipeline Corrosion Monitoring

Pipeline corrosion monitoring in Canmet Materials Technology Laboratory, NRCan, Ottawa, NACE International — Corrosion 2008 Conference and Expo, New Orleans (Louisiana, USA 16-20 March, 2008).
• Refineries use reactors and pressure vessels to transform heavy oil into synthetic crude oil.
• The upgrader reactors are operated at very high temperatures, exceeding 500 °C.
• Due to the thermal stress exerted on the structure of the reactor, a wall-thinning problem might occur, resulting in conductive heat dissipation.
• Without the proper sensing technology, the refinery operator might prematurely shut down operations to perform untimely maintenance, or worse yet, the problem might go unnoticed, resulting in a catastrophic accident.
Pipeline Buckling Detection

* Pipeline buckling detection in TransCanada Pipeline Ltd, Calgary, and C-FER Technology, Edmonton
Coating materials and maximum sustainable temperatures

<table>
<thead>
<tr>
<th>Material</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV-cured acrylate</td>
<td>100</td>
</tr>
<tr>
<td>UV-cured dual acrylate</td>
<td>150</td>
</tr>
<tr>
<td>Polyimide</td>
<td>400</td>
</tr>
<tr>
<td>Copper+polyimide</td>
<td>400</td>
</tr>
<tr>
<td>Aluminum</td>
<td>450</td>
</tr>
<tr>
<td>Copper alloy</td>
<td>600</td>
</tr>
<tr>
<td>Gold</td>
<td>700+</td>
</tr>
</tbody>
</table>
Power Utility

- OPGW Monitoring
- Power Cable (Submarine Cable) Monitoring
- Temperature profile monitoring of an air-cooled gas generator
OPGW Monitoring

• Monitoring the working status of OPGW
• Abnormal event found and located
• Event caused by broken strand, lightning, frost covering, change of strain, etc.
The OPGW is located from Smith Falls to Merivale-Ottawa, Ontario, Canada.

The total fiber length was close to 140 km.

The BOTDA located in Merivale-Ottawa made measurements as often as once every 60 minutes starting in June 2012 and continuing till July 2013.
**OPGW Strain Monitoring**

* Power line/OPGW monitoring in Hydro-Québec, Montreal

![Strain Monitoring Diagram](image)

- Aluminum Clad Steel Wire
- Central Stainless Steel Tube
- Optical Fibers
- Aluminum Alloy Wire

![Strain Graph](image)

- FWHM
- 50 MHz
- 12434 MHz
- 0.0 kN
- 34 kN
- 127 kN

![Power Line Setup](image)

- Ordinary cable: 60 m
- Stress region: 93 m, 2 loose regions & stress region

![Control Room](image)

- Control room
- Brillouin scattering sensor system

51
High Voltage Underground Cable with Fiber
Temperature profile monitoring of an air-cooled gas generator
Concrete Beam/Highway Monitoring

Concrete beam/Highway monitoring on HW40/University of Sherbrooke, Dr. Brahim Benmokrane
GeoDetect With Embedded Fibers
Christchurch Northern Corridor (CNC) – Measuring settlement with fibre optics

CNC ALLIANCE PROJECT FEATURES
Project engineer Stephen Coleman talks about innovative fibre optics to measure settlement

New Zealand Government
Crack Detection

Crack detection in University of California, Irvine, Dr. Maria Feng, 19th International Conference on Optical Fiber Sensors, Perth (Australia, 14-18 April 2008).
Crack Detection

Crack detection in University of California, Irvine, Dr. Maria Feng, 19th International Conference on Optical Fiber Sensors, Perth (Australia, 14-18 April 2008).
Brillouin Sensor Monitoring of Telecom Fibers

- Detects minor events that are too small to be seen by OTDRs.
- Can replace OTDRs for monitoring fibers.
- Can be used to monitor new or existing fiber installations.
- Permits performance monitoring of fibers above or below ground.
- Avoids unnecessary replacement of old fibers, saving millions of dollars in installation costs.

Yogokawa’s results from AT&T’s old telecom fiber, very broad Brillouin spectrum, which results in poor resolution and accuracy.

OZ’s results from AT&T’s old telecom fiber, very narrow Brillouin spectrum, which results in high resolution and accuracy.
The Cost of Catastrophic Failure

* Example: Druzhba Pipeline July 2006
* Small 50 cubic meter leak results in:
  * Interruption of $100M/day pipeline
  * Global spike in oil prices
  * Report of environmental catastrophe
  * Months of investigation and ecological monitoring
* Single point of failure in 3,000 km pipeline
The Cost of Catastrophic Failure

- Example 2: Nigerian Pipeline July 2006
- Accidental leak
- 180,000 barrels / day shutdown
- $180,000 \times $74 = $13M per day
- 10-day shutdown = $130M
- Brillouin operation $\ll$ $1/m/year
- **Single production shutdown far exceeds lifetime sensor operating costs.**
Acknowledgements

* University of California, Irvine, Dr. Maria Feng
* University of Ottawa, Dr. Xiaoyi Bao
* University of Sherbrooke, Dr. Brahim Benmokrane
* TransCanada Pipelines Limited (TCPL)
* C-FER Technologies
* Canmet Materials Technology Laboratory, NRCan
* Hydro-Quebec
* Southwest Research Institute®
* Tencate Geosynthetics
* NZ Transport Agency
* Christchurch Northern Corridor
* CNC Alliance Project
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