Oil Pipeline On-Line Geotechnical Risk Monitoring

A Case Study

Colombia, 2012 - 2015
The Challenge

• Buried oil & gas pipelines are susceptible to accumulated strain, bending and possible rupture effects from soil movements and other geohazards.

• Ecopetrol in Colombia desired to have a means for real-time, on-line monitoring of critical sectors of their extensive pipeline network and get advance warning of over-stresses, bent or ruptured oil pipelines.

• The installation demanded a solution that is intrinsically safe to avoid any possible explosions, immune to lightning effects and electric shorts, resistant to humidity and contact with water, as well as capable of remote interrogation.

The Solution

• Use optical fiber FBG temperature-compensated strain sensors mounted around the perimeter of the pipeline in critical locations.

• Accumulated strains and induced bending are determined by using a set of 3, radically equidistant strain sensors.

• Sensor are installed on pre-determined locations where geohazard risk is known to happen or suspected. Periodic strain readings are taken bi-weekly manually, over the entire pipeline network operated by Ecopetrol.
The Results

- 71 different critical geohazard sectors along Ecopetrol’s oil transportation pipeline network were instrumented with anywhere from 1 to 10 (triad) FBG strain sensing belts.

- Over 300 strain sensors were installed with only 3 sensors damaged during installation procedures. Each sensor installation required 2-3 days of installation (not counting excavation and re-burial operations).

- The monitoring system has been in operation since Spring of 2013. Data is taken manually every fortnight by a field crew that visits each sector and records data.

- Valuable behavior of critical pipeline sections has been obtained, quantifying accumulated axial strains, pipeline bending and potential sites for incipient pipe rupture or leaks.

- To date, 2 serious pipeline failures have been averted. Multiple locations with accumulated strains have been identified and appropriate stress-relieving pipeline activities carried out.
Ecopetrol’s Pipeline Network

- Ecopetrol’s transportation network consists of approximately 5,269 kilometers of main crude oil pipeline networks connecting various fields to the Barrancabermeja refinery and Reficar, as well as to export facilities.

- Pipelines vary in outside diameter from 10” to 48” inches.
# Project Overview

<table>
<thead>
<tr>
<th><strong>Aim</strong></th>
<th>Provide early warning to Ecopetrol pipeline operators about possible pipeline mechanical bending or rupture from soil movements.</th>
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</thead>
<tbody>
<tr>
<td><strong>Location</strong></td>
<td>Colombia</td>
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<tr>
<td><strong>System Integrator</strong></td>
<td>Salazar Ferro Ingenieros, Bogota, Colombia</td>
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<tr>
<td><strong>Customer</strong></td>
<td>Ecopetrol</td>
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<tr>
<td><strong>Date</strong></td>
<td>Project Started in Fall of 2012. Installation completed Spring of 2013. In operation since.</td>
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<tr>
<td><strong>Instrumentation</strong></td>
<td>(7) Micron Optics sm125-500 Optical Sensing Interrogator</td>
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<tr>
<td><strong>Sensors</strong></td>
<td>(&gt; 300) Micron Optics os3155 temperature-compensated FBG strain sensors</td>
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<tr>
<td><strong>Software</strong></td>
<td>Micron Optics Enlight software</td>
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</tbody>
</table>
Sensor Used: os3155 (FBG T-compensated strain sensor)

FBG sensor for thermal compensation

FBG for strain sensing
Sensor Lay-out

Flow direction

Axial strain

$\varepsilon > 0$

$\varepsilon < 0$
Sensor Installation

Sensor pre-placement

Sensor inspection & verification

Removal of pipeline coating

Sensor Placement prior to welding
Sensor Installation

Spot-welding of sensors

Aspect of welded sensor to pipe

Sensors are covered with impermeable patches

Aspect of completed installation
Sensor Installation

- Sensor wrapping protection
- Pipeline re-burial
- FO cable junction terminal
Data collection

Each geo-hazard location along the pipeline network has a set of 1 to 10 separate strain-sensing FBG sensor belt. Each “sensor belt” had its strain readings manually recorded bi-weekly, by connecting the sm125 interrogator to connector terminated fibers protected inside the shown tubular housings. This prevented damage from wild animals or vandalism.
Graph illustrates the accumulated axial strain on a pipeline point over a two-year period. It can be observed that the pipeline is gradually stretched due to soil movement over time, reaching strains > 1000 µε, until the pipeline is stress relieved.
Example of time-accumulated strains

Geohazard pipeline location (pk 195+700).

Notice how the points outside the geohazard zone remain stable (left graphs) while those in the critical region, display accumulated strains and bends caused by soil movement.
• The FBG strain sensors provide valuable advantages to the customer in this project such as:
  • fast and easy installation
  • accurate data
  • Immunity to electric interferences (storms or electric motors near to the pipeline)
  • no need for calibration in each measure (as resistive and vibrating string based sensors).

• Periodic monitoring of accumulated pipe strains and bending on critical locations were geohazard risks were identified or anticipated.

• Measured data provided a valuable operations tool for:
  • Stress relieving of severe pipeline stresses
  • Early warning of potential pipe ruptures
  • Better understanding of time evolution of mechanical effects on pipeline network
  • Help define new maintenance protocols and set safety strain thresholds

• Saved the customer millions of dollars in prevented pipeline ruptures and associated environmental remediation costs.
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