Praetorian Fibre Optic Sensing

Power and Data Cable Monitoring

Hybrid Distributed Acoustic and Temperature Sensing for Underground Infrastructure

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Praetorian Fibre Optic Sensing for Power and Data Cable Monitoring

- High Voltage Underground Power
- Communication Cables
- Fibre Optic Networks
- Hybrid DAS and DTS

The Problem

Underground Infrastructure; once installed needs to stand the test of time. In some cases data cables, wires and power transmission lines can be expected to have an operating life from a few decades up to almost a century without the possibility of a visual inspection.

Monitoring for wear, damage or corrosion of the cable is extremely difficult and often power failure or data outage is the first sign of a problem.

Often, these assets are installed in areas that have multiple uses by various stake holders and in the event of a failure or damage can be logistically difficult and expensive to access for repair.

Due to their accessibility when compared to overhead lines, it should also be noted that third party intrusion (both accidental and nefarious) is a much greater threat to buried power transmission lines. Subsequently risk of exposure to Arc Flash from live conductors and potential for electric shock or electrocution are much greater. As well as the possibility for optical cables to be damage leading to extended telecommunication outages.

Additionally performance of these cables is constantly degrading over time due to material and environmental factors. This effect although slow and unpredictable is inevitable and ultimately causes failure of the conductor on optic. Location of these faults is a major challenge and a significant contributor to downtime.

Ultimately to manage these risks a method of around the clock monitoring is required that can be fitted during construction or retrofitted to existing infrastructure. Due to the long runs transmission cables need to cover, traditional instrumentation would need to be installed at regular intervals along the cable run and require supporting infrastructure (power and communications) to each device, an entirely impractical proposal.

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The Solution

To solve this problem a solution would need to do the following:

- Detect issues as a distributed sensor rather than a point sensor
- Require no additional field infrastructure such as power or communication
- Operate in real time
- Low cost per meter
- Autonomous detection with low false alarm rate
- To be preventative rather than reactive

Until the advent of Distributed Fibre Optic Sensing systems, it was almost impossible to achieve any of these technical requirements this application required, therefore the first notice an asset operator would get would be a disruption to their network.

Principle of Operation

The Praetorian system interrogator unit is connected to one end of a fibre optic cable which is attached to or buried with the cable or infrastructure being monitored. The interrogator produces rapidly pulsed laser light set at a precise frequency that excites the fibre and causes it to be responsive to physical changes around it. Some of this light is reflected back (backscattered) to the light source where the interrogator records and analyses looking for changes to its colour relating to physical effects in the application.

Time of Flight

Locations of events are able to be accurately determined by a method called time of flight. The amount of time from sending the laser pulse to receiving a return signal is recorded. Due to the internal properties of a fibre optic core, the speed of light through a fibre is consistent at approximately two thirds of the speed of light through a vacuum (around 400μs for a 40km round trip). As this is consistent, the return time can be used to calculate a distance on the fibre.

Vibration Detection

In Praetorian, an optical effect called Rayleigh backscatter is used to observe vibrational effects on a fibre. In a fibre optic core, backscatter is the light that reflects off natural imperfections and polarizations within the fibre and returns to the light source. The return light gets diffracted into different frequencies similar to light moving through a prism and Rayleigh backscatter is one of these diffracted frequencies. The amount of compression that vibration from an event (such as intrusion, partial discharge or cable vibration) causes on the core determines the strength of the Rayleigh component of the backscatter. In this way the intensity and frequency of the vibration is measurable by recording the behaviors of the Rayleigh backscatter component. This change in intensity and frequency is used to determine the presence and position of a disturbance to within one meter.

To being classified as an alarm the amount of time, the dominant frequencies and the relative intensity all need to be present within pre-determined thresholds. This reduces the amount of false signals that move in to an alarm condition.

Functionality

Praetorian Fibre Optic Sensing (FOS) uses a combination of Distributed Acoustic Sensing (DAS) and Distributed Temperature Sensing (DTS) to protect underground buried assets. By exciting a fibre optic core within a cable the Praetorian Interrogator is able to utilise the fibres as distributed network equivalent to up to 1.6 Million individual vibration, temperature and strain sensors.

Because Praetorian utilises a number of different sensing methods it is possible to observe events in a number of physically independent ways, consequently Praetorian is inherently resistant to taking a given reading and giving a false alarm due to the requirement for multiple physical effects to simultaneously occur at the same location to signify an event and trigger an alarm.

Through a combination of distributed vibration, temperature and strain monitoring it is possible to determine multitudes of different physical events along a cable, including but not limited to:

- Detection of partial discharge
- Detection of hot spots
- Early alert of third party intrusion (accidental or nefarious)
- Conductor break detection
- Ground condition assessment
- Prevention arc flash events from conductor contact
- Detection of optical Loss
- Detection of Fibre Break
- Detection of pit or trench lid being opened
- Determination of network operational status (thermal loading)

Praetorian also Geo-tags alarms allowing security or maintenance teams to be able to respond immediately.

Distributed Acoustic Sensing (DAS): Third Party Intrusion detection

Often the primary way of preventing damage to buried assets is to prevent them being struck and damage by third parties. As significant excavations are generally required to unearth buried assets due to their depth of cover the process of excavation takes sufficient time that a warning provided quickly enough can give an operator enough time to alert the third party to the dangers below them.

Different digging events generate different signals which are picked up by the monitored fibre that are either part of or buried alongside the asset.

Temperature Detection, Real Time Thermal Rating

At the same time that the interrogator is monitoring for vibration Praetorian will continuously hunt for temperature spikes along its length. It does this by scanning a separate fibre within the cable and looking for changes to another component of backscattered light called Brillouin scattering. The system can be calibrated to run very quick (a few seconds), lower accuracy (±1°C) scans of the fibre for temperature changes or to take a slower (half a minute) more detailed scan for maximum accuracy (±0.25°C) of temperature to sense even the smallest changes.

Due to the relatively consistent ground temperature it is possible to use dynamic cable temperature to undertake a calculation known as RTTR (Real Time Temperature Rating). Using RTTR it is possible to observe the amount of current flowing through a conductor based on the supply power and the cables mechanical properties and allows for fine control and monitoring for cable load during stable and emergency scenarios.

RTTR systems are able to indicate whether areas are stressed (overheated) or in fact have more capacity than originally anticipated. Using RTTR can assist with network load spreading and allow for direct infield monitoring of cables when running in an overload condition so that maximum operating temperatures can be observed and controlled before emergency conditions can occur on the network

Typically the actual maximum temperature reading of each configured cable section and the actual electrical current reading are computed to build the dynamic cable rating of the installation, based on IEC 60287 and IEC 60853 standards.

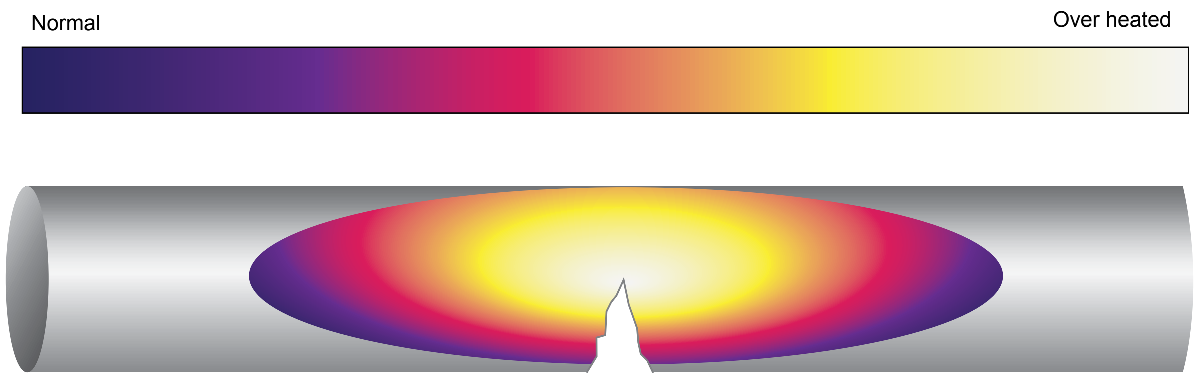
The key inputs to the RTTR cable rating modeling are required as follows:

- Cable size and type, installation configuration (cable laying formation)
- Soil ambient temperature
- Soil thermal resistivity and cable backfill material thermal resistivity if used
- Real time loading

The outputs from a RTTR used in a buried cable environment include:

- Real time conductor temperature along the power cable
- Emergency ratings – this can be for a range of times from typically 30 minutes to 48 hours+
- Transient calculations for Time/ Current/Temperature

Heat Image under the thermal detection



Temperature Monitoring: Temperature Profiling

The use of distributed temperature monitoring for ground temperature monitoring is a common supplementary use of fibre optic sensing DTS systems. Benefits include:

- Monitoring of annual and seasonal changes in ground condition
- Ground freezing and flood monitoring
- Ground water table interaction
- Ground temperature monitoring for material degradation monitoring.

Live Optical Condition Monitoring

By analysing the resultant return signal from praetorians Distributed Acoustic Sensing (DAS) light pulse a number of optical fault conditions can be detected due to the presence of a loss of return light. Time of flight is used to determine the location of that loss where it occurs. Different optical loss conditions can be detected including (but not limited to):

- Micro-bends
- Macro-Bends
- Connector losses
- Fusion Splice losses
- Impurities
- Fibre Cut
- Moisture and Hydrogen infusion loss.
- Time based Degradation.

Losses are able to be monitored over time and alert thresholds set to allow plan maintenance well ahead of total failure conditions.

Advantages

- Praetorian can function where the cable cannot be visually inspected (due to burial)
- Fibre Optic Sensing detects not only the presence of the fault of failure but its specific location
- Praetorian is extremely sensitive, detecting sounds well below frequency human hearing can manage
- Due to the use of “long haul” single mode fibre Praetorian is able to detect faults over long hauls
- Existing Fibre optic data infrastructure may be utilised
- System is passive, no electricity is required in the field
- No maintenance or calibration require after commissioning
- Self diagnostics monitor the unit’s condition and maintain optimum performance
- Not effected by electromagnetic fields (EMF), lightning or weather events
- Easy, low cost installation with cable
- Low cost per meter

Unique Features

Praetorian has a number of unique features which make it a market leading technology. The Field Programmable Gate Array (FPGA) allows for ultra-fast parallel processing of the returned signals meaning that Praetorian does not have to time splice or “skip” sections of time to keep up with incoming signals.

One distinct advantage with the Praetorian system is that it is able to work such that it is immune to the effects of a broken or cut fibre. The unit can be attached as a loop to both channels on independent fibres and in the event of a cut will report the damage, but continue to monitor the fibre on both sides up to the cut. Alternatively, if installed in a non looped fashion Praetorian will monitor the position of the fibre end and check for any change to this. It can instantly identify a cut to the fibre.

In all distributed acoustic fibre sensors, the detected signal level has certain variations depending on the polarization state of the received signal which produces scattering of the signal. This scattering can be constructive interference or deconstructive interference, and to date there has been no ability to compensate for this scattering which is referred to as signal fading.

HAWK has patented an effective solution to overcome signal fading, where small signals can be detected without fading. Unlike systems restricted by Multimode LED light sources Praetorian uses a highly stable laser controlled to within ±0.04pm allowing the system to handle two independent sensing channels of up to 40km each without any loss of measurement in switching or time splicing.

Praetorian’s main technical advantage is its hybrid and modular design. Praetorian can be configured to monitor a fibre for Distributed Acoustic Sensing (DAS), Distributed Temperature Sensing (DTS) or both Distributed acoustic temperature and Distributed Acoustic Sensing Side by side.

In addition Praetorian can be configured in either a dual or single channel configuration, the dual channel configuration being available in Dual DAS, Dual DTS or the most popular configuration the Hybrid DAS/DTS configuration.

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Technical Specifications

Category	Parameter	Description
General	Sensing Element	Fibre Optic Sensing Cable
	Number of channels	1 or 2
	Interrogator operating Temperature	0-50°C
	Unit operating Humidity (max)	85% non-condensing
	Dimensions	4RU 19” Rack Enclosure (190x600x490mm)
	Weight	25kg
	Power Supply	110-240VAC (50-60Hz), 24VDC
	Power consumption	<200W
Performance	Sensing Range (DAS)	Up to 40km per channel
	Sensing Range (DTS)	Up to 80km Loop Per channel
	Spatial Resolution	250 or 500mm
	Frequency Response	1Hz-120kHz (Range Dependant)
	Dynamic Range	50dB
	Temperature sensing range (cable)	-30°C to 200°C (special options for temps up to 800°C and down to -200°c available)
DTS Performance	Accuracy	±0.25°C
	Resolution	0.01°C
	Scan Time	1-2 Minutes (Depending on Temperature Parameters)
	Temperature Sensing Range	-250°C to 700°C
Technical	Light Source	Laser (Infra red) Class 1M
	Laser Wave Length	1550.12nm (nanometres)
	Laser Stability	±5pm (picometers)
	Acquisition rate	400MHz
	Processor Acquisition Rate	64Bit (Ultra high speed)
	Operating System	Linux
	Output	Modbus Ethernet TCP/IP (Standard), Relay, USB, SCADA or User Specified
	Remote Interfacing	Ethernet and 3G/4G enabled
	Processer architecture	Field programmable gate array (FPGA)
	Data Storage (Removable)	2x 2TB HDD (removable)
	Data Storage (Internal)	128GB Solid State Drive

Other Uses

This document covers the use of the Praetorian Fibre Optic Sensing system utilising the underground cable protection and monitoring software suite and hardware. However there are a large number of other applications Praetorian is well suited to monitor.

These include but are not limited to:

- Perimeter Intrusion Detection System (PIDS) Security
- Pipeline Leak Detection System (LDS)
- Conveyor Malfunction and Fire Detection
- Fire Detection Including Road and Rail Tunnels
- Infrastructure Strain and Stress Monitoring
- Borehole Condition Monitoring
- Solutions for Railways and Metro
- Hot Spots & Insulation Damage on Process Equipment

Part Numbering

Model

FOS Praetorian Fibre Optic Sensing Interrogator

Power Supply

B 24VDC

U 110-240VAC

Sensing Method

AXX Distributed Acoustic Sensing

TXX Distributed Temperature Sensing

ATX Hybrid Distributed Acoustic and Temperature Sensing

Channel

01 Single Channel

02 Dual Channel

1M Single Channel with Multiplexer

2M Dual Channel with Multiplexer

04 Four Channel

Mounting

4R 4RU Rack Mount

Communications

M Modbus TCP/IP

Software Options

CMS Cable Monitoring System

Version

X HAWK

FOS U ATX 02 4R M CMS X

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