integrated Cathodic Protection (iCP) Surveying with an Autonomous Underwater Vehicle

Brian Claus, Ph.D., Matthew Kowalczyk, Eng. – OFG
Craig Donald BSc. Dip Eng. – ISES Technical Services

www.oceanfloorgeophysics.com  www.ises.tech
OFG Company Overview

**AUV Survey Operations**
- OFG owned and operated “Chercheur” Hugin1000
  - Equipped with HiSAS, MBES, SBP, HiRes Camera, ADCP, water geochemistry, Self-compensating magnetometer
- OFG/ISES integrated Cathodic Protection (iCP) system
- Operational Support for Third party AUV’s

**AUV Sensor Development and Supply**
- OFG Self-Compensating Magnetometer (SCM).
  Installed in > 20 AUVs
- Production and sale of low impedance Ag/AgCl marine electrodes
- OFG/ISES integrated Cathodic Protection (iCP) system

**Development and Operation of Other Geophysical Systems**
- Vulcan CSEM towed array
- AUV borne CSEM
- ROV borne EM and magnetometer systems
- 3D Vertical Cable Seismic
- Towed Array Marine Induced Polarisation System

**Full Service Provider**
- Project Management
- Survey and Mission planning
- AUV Training
- Data Analysis and Interpretation
OFG Core Competencies

Strong Geophysical and AUV background (Company founders)
- OFG formed in 2007
- Mineral and Hydrocarbon Experience

Extensive Operational Experience:
- Highly experienced geophysicists, engineers, AUV and ROV operators
- Extensive experience in mobilising geophysical systems onto vessels of opportunity globally

Specialised expertise in sensor design and integrating instrumentation
- Including electromagnetic (EM) systems, geochemical sensors, sonars, navigation systems

Strong Technical Alliances

Full Service Provider
- Specialised in providing bespoke subsea geophysical solutions from planning, implementing, data processing and interpretation
Founded in 2003 as Inspection Survey & Integrity Services, ISES has conducted many thousands of kilometres of subsea pipeline CP survey and many hundreds of underwater structural surveys. Supporting major Oil & Gas companies worldwide, using a suite of in-house hardware & software developed to undertake subsea CP Survey, Analysis & Reporting services.

Capabilities include:

- Subsea cathodic protection survey analysis & reporting services
- Subsea structural CP retrofit designs and optimization,
- Harbour cathodic protection design, installation and maintenance
- Supply of subsea inspection project services and personnel
- Project management
- Data management & historical data trending
- Maintenance of CP system integrity
STABCON® – Single Cell Stab & Continuous CP Monitoring System

CP- DAS Subsea Pipeline CP/FG Logging System

Trailing Wire CP Survey
Why do Cathodic Protection (CP) inspection?

1. Check the CP system’s operational integrity
2. Detect any corrosion problems and to adjust/retrofit before any major failure
3. Confirm integrity of the structure/pipeline & CP system
4. Collect data to reduce future inspection requirements
5. Adherence to Regulatory Authority Requirements
Cathodic Protection Methods

Sacrificial Cathodic Protection
- Electrical bond (cable)
- Seawater
- Pipeline
- Electron flow
- Anode
- $m \rightarrow m^+$
- Current flow

Impressed Current Cathodic Protection
- Above Water
- External D.C. Power Supply
- Seawater
- Pipeline
- Electrical bond (cable)
- Impressed current Anode (Inert)
- Current flow
Depolarisation Period (C) is when anodes are reaching end of design life with reduced efficiency. *Accuracy of CP measurements most critical.*

Under Protected Period (D) is the critical period when protective level has dropped below -800 mV. Danger of failure from corrosion at localised positions.
Twin Cell CP/FG Survey Method

Equi-potential Field Lines
-1070mV
-1040mV
-1010mV
-950mV
-1000mV
2 metres
3 metres
100+ metres

Remote Half Cell & Contact
ROV with Single Cell Probe

Twin Cell CP/FG Survey Method

ROV with Twin-Cell CP/FG Probe
# Twin Cell CP/FG Survey Method

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| ROV MOUNTED (TWIN CELL CP/FG SYSTEM) | • Contact Potential (CP) mV  
• Continuous CP/FG v KP.  
• Electrical Field Gradient (FG) $\mu$V/cm = microvolts/cm  
• Sensitivity 1mV & 1$\mu$V/cm | • Potential & Field Gradient profiles  
• Anode contact potential.  
• Anode current (mA)  
• Areas of current drain  
• Estimation of anode remaining life | • Requires dedicated support vessel = high cost  
• Slow survey speed (~1 km/hr)  
• Regular Calibrations contacts required  
• Probe orientation and distance can limit accuracy  
• Limited application on buried pipelines |
FG signal attenuated by distance.

Field Gradient (millivolts per metre)

Pipeline condition
- Fully exposed
- Half buried
- Crown visible
- Buried

Axial Distance from pipe surface (metres)
Horizontal Offset Errors

TRUE FIELD GRADIENT = \( \frac{V_3 - V_1}{d} \) \( \mu V/cm \)

WITH PROBE AT OFFSET DISTANCE FG = \( \frac{V_4 - V_2}{d} \) \( \mu V/cm \)

HORIZONTAL OFFSET ERROR = \( \frac{((V_3 - V_2) - (V_4 - V_2))}{d} \)
The AUV-iCP Concept: integrated Cathodic Protection System

- Use AUV pipe tracking and E-Field system concurrently to accurately locate gradient field measurements relative to pipe
- Current flow through the pipe from Cathodic Protection can then be mapped
- Determine:
  - Level of cathodic protection
  - Activity of anodes
  - Leakage currents in pipe as proxy for pipe damage/non-uniformity
The AUV-iCP Concept Requirements

• Signal amplification with high signal to noise ratios
  – System sensitivity < 0.01 uV/cm

• Highly accurate measurement of distance and orientation from sensor array to pipeline, continuously measured.

• Seawater resistivity constantly measured.

• System sampling rate >250Hz
  – Frequencies of interest are between 1 Hz and 0.01 Hz based on anode spacing and vehicle speed.
The AUV-iCP Concept

Precision Navigation
Real-time accuracy of ~2m with HiPAP USBL system

Pipe Tracking
Real-time tracking of pipe using HiSAS/MBES provides ~cm level positioning relative to pipe

E-Field Gradients
Gradient measurements in 3-axis

Cathodic Current Estimation
By combining these three systems the cathodic current flowing through the pipe may be estimated
AUV-iCP Deployment

- OFG initially developed and deployed the E-field system on AUV for mineral exploration
- OFG’s AUV Chercheur, a 3000m HUGIN 1000,
  - Can perform pipe inspection and tracking using MBES, HiSAS, magnetometer, and photos
- Presently outfitting Chercheur with E-Field iCP System
Chercheur AUV-iCP Integration

• Electrical Noise tests with OFG’s HUGIN AUV “Chercheur” for two configurations
  – “Caribou” – Antenna array with wide spacing of electrodes using “antlers” on AUV
  – “Shark” – Antenna array with electrodes affixed closely to hull of AUV

• Similar Electric Self Noise Levels < 0.01 uV/cm → ✔ Suitable for AUV-iCP

Above: Electrode tests with the HUGIN AUV
Right: Noise spectrum tests with all instruments on, off and only EM (no AUV)
Chercheur AUV Electrical Noise Tests

“Caribou” Configuration
Location of Electrode Array on AUV
Chercheur AUV Electrical Noise Tests

“Shark” Configuration
Location of Electrode Array on AUV
Chercheur AUV Electrical Noise Tests

Electrical noise tests run on:

“Caribou” Configuration:
- Aft, Port, Starboard, Forward 1, Forward 2, Vertical electrodes

“Shark” Configuration:
- Along AUV axis electrodes, Across AUV Axis electrodes, Vertical Axis AUV electrodes

Sample noise spectrum tests with all instruments on, off and only EM (no AUV)
Simulation AUV-iCP with MBES/Photos

- Concurrent pipe tracking with MBES, Photo and E-Field Measurements
  - Altitude - 4 meters
  - Cross Track distance – 0 meters
  - Speed - 3.8 knots

Simulated values:
- **Pipeline Current Density**
  - 20 mA/m^2
- Φ 10 cm unburied pipe
- 150 m anode separation
- Anode at 0 meters
- 100 mA leakage at -50 m
Multi-Segment Simulation

- Flight at 5 meters altitude directly over pipe
The OFG/ISES AUV Mounted E-Field iCP System

In Summary

• Highly sensitive 3-axis Field Gradient 0.01µV/cm
• Concurrent integrated sensor operation
• Anode current measurement
• Detection of “active” coating damage
• Identification of current drain areas
• Significantly Higher Survey Speeds than ROV (~7km/hr)
AUV-iCP Conclusions Based on Simulation and Field Tests

• The passive AUV mounted EFG system has the capability to accurately detect, quantify and locate Field Gradient (FG) activity along a pipeline route at significantly higher speeds than an ROV survey.

• Signal accuracy was not significantly reduced by either vertical or horizontal standoff distance of the AUV from the pipeline.

• The system can gather multiple data sets from other sensors simultaneously without degrading the received signals due to systems operations noise.
Europe
ISES Technical Services Limited
1st Floor, Block 7, The Altec Centre
Minto Drive, Altens Industrial Estate
Aberdeen AB12 3LW, Scotland
Tel: 01224 874440
Fax: 01224 872211

Web Site: www.ises.tech
Email: craig@ises.tech

Asia Pacific
ISES Technical Services PTE Ltd.
No 38 Loyang Drive, Unit 01-03
Loyang Industrial Estate
Singapore 508960
Tel +65 65 467228

Malaysia
Inspection Survey & Integrity Services Sdn Bhd
CT-10-07 Subang Square Corporate Tower
Jln SS15/4G, 47500 Suband Jaya, Selangor, Malaysia
Tel: +6 03 5635 9500 / 9850 / 9750
Fax: +6 03 5635 9655
Ocean Floor Geophysics Inc.
B108 – 9000 Bill Fox Way
Burnaby, BC
Canada V5J 5J3
E: Matthew.Kowalczyk@OceanFloorGeophysics.com
T: +1-778-654-7781