Institution: University of Leeds		
Unit of Assessment: UOA 09		
Title of case study: Large stand-off magnetometry for non-invasive buried pipeline inspection		
Period when the underpinning research was undertaken: 2011 – 2016		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Prof. Ben Varcoe	Chair of Quantum Information	2006 – present
Period when the claimed impact occurred: 2014 – date		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact (indicative maximum 100 words)

Pipeline operators are required to maintain the integrity of their pipelines. However, a large majority of the world's pipelines are not suitable for *in situ* in-line inspection, and require an above-ground inspection approach. In general, 90% of apparent pipeline defects identified by such approaches prove not to be associated with pipeline corrosion, and hence result in unnecessary excavation, infrastructural disruption, and expense. The University of Leeds has developed large stand-off magnetometry instrumentation (UNISCAN™), commercialised by Speir Hunter Ltd, which enables accurate and cost-effective remote sensing of pipework defects. Since 2014, over 700 km of pipeline in Europe, North and South America, Africa, Asia and Australia have been inspected with the Leeds instrumentation.

2. Underpinning research (indicative maximum 500 words)

The underpinning work was undertaken as a collaboration between the Experimental Quantum Physics group (School of Physics & Astronomy) and the Ultrasonics and Embedded Systems group in (School of Electronic and Electrical Engineering) University of Leeds, led by Professors B **Varcoe** and S **Freear**, respectively. Both have a long-standing track record of expertise in industrial measurement and sensing, with a focus on the development of bespoke electronics and signal processing algorithms.

In 2011, **Freear & Varco** received funding from the National Grid Plc **[i]** to study pipeline inspection, in partnership with the SME Speir Hunter Ltd, which was established at the same time to develop and exploit stand-off magnetometry detection technologies. Working with colleagues in the School of Electrical and Electronic engineering Varcoe *et al.* began an investigation into the relationship between stress and the resultant magnetic field in steel bars and small-scale pipelines, combining laboratory experiments with finite element modelling. From the experimental magnetometry measurements, they were able to build models that enabled the determination of stress at varying distances from the pipework, termed 'large stand-off magnetometry' **[1]**. Algorithms were then developed to process and analyse the magnetic data and determine stress concentration zones, which in turn relate to critical pipeline features such as pipeline girth welds, damage/defects and depth of coverage. Field observations were also performed on above-ground gas pipelines to verify performance **[2]**.

Patents were filed and licensed to Speir Hunter **[3–5],** and the research was encapsulated into two distinct packages (all designed, constructed and tested at the University of Leeds) to facilitate commercial exploitation. First, a portable, robust, magnetometry based scanning instrument was created, known as UNISCAN™. Second, an analysis software suite (UNISCAN Tools™) was designed, combining finite element models and experimental findings into algorithms suitable for processing the large datasets generated from field data. The complete system is unique in providing a non-invasive method for assessing pipeline integrity through a process termed Stress Concentration Tomography (SCT™).

A real-time, portable, measurement system incorporating magnetometry measurements with millimetre scale positional accuracy was then designed and constructed by the University of Leeds. Initial field trials were performed by the University with National Grid Plc on over 5 km of pipework in Gasunie Germany (2012). A further 7 km of pipeline was then measured with Enbridge Inc in Canada and the USA in 2013, and the results were verified against the best available alternative analysis techniques. An extensive survey was also undertaken of National Grid pipelines and surface pipework in Pannal near Harrogate in 2015–2016, which involved anomaly and weld detection trials. Furthermore, additional research funding **[ii]** was received in 2014 from the Energy Networks Association to develop the technology further in collaboration with Speir Hunter, National Grid and Det Norske Veritas Germanischer Lloyd (DNV GL), which enabled expansion of the scale of verification studies, with the systems rigorously tested with commercial partners National Grid (UK), Gasunie (Germany), Enbridge (Canada), and Shell (Canada /USA).

3. References to the research (indicative maximum of six references)

[1] SGH Staples, C Vo, DMJ Cowell, S Freear, C Ives, and **BTH Varcoe**. Solving the inverse problem of magnetisation–stress resolution. *Journal of Applied Physics* 113 (13), 133905 (2013). https://doi.org/10.1063/1.4799049

[2] CK Vo, SGH Staples, DMJ Cowell, **BTH Varcoe**, and S Freear. Determining the Depth and Location of Buried Pipeline by Magnetometer Survey. *Journal of Pipeline Engineering and Practice* 11(2), 04020001 (2020). https://doi.org/10.1061/(ASCE)PS.1949-1204.0000438

[3] S Freear, **B Varcoe**, DMJCowell, SGH Staples, C Vo, WO/2013/128210 – Fault Detection for Pipelines. https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2013128210

[4] S Freear, **B Varcoe**, DMJCowell, SGH Staples, C Vo, WO/2013/128212 – Fault Detection for Pipelines. https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2013128212

[5] S Freear, CK Vo, **B Varcoe**, DMJ Cowell, SGH Staples, CL Cookson, WO/2018/046947 – Pipeline Mapping System. https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2018046947

Developing the science – grant support

[i] *Pipeline inspection*, 2011 – 2014 GBP566,000, National Grid

[ii] *Stress concentration tomography*, http://www.smarternetworks.org/project/nia_nggt0044, 2014 – 2016, GBP504,000 (part of a GBP1,200,000 Network Innovation Allowance award funded by the Energy Networks Association https://www.energynetworks.org/ in collaboration with the National Grid and GL/DNV).

4. Details of the impact (indicative maximum 750 words)

The National Association of Corrosion Engineers (NACE) defines the international standards for corrosion prevention and control, with a pipeline integrity management system providing the overarching, integrated framework for effective pipeline asset management.

Pipeline asset owners are required by regulators to inspect the integrity of the pipeline coating, and to excavate and investigate the condition of the metal under a coating whenever a coating defect is detected. NACE has three accepted practices for ensuring pipeline integrity, operational lifetime, and compliance with the associated legislation: 'in-line inspection'; 'hydrostatic testing'; and, 'direct assessment'. 'Direct assessment' (DA) is used when the other two evaluation techniques are not practical and uses surface survey data in the assessment.

The UNISCAN™ product, based entirely on University of Leeds original research, and marketed by Speir Hunter as a stress concentration tomography (SCT) system, is now accepted as a DA technique within NationalGrid (UK) for identifying the presence of stress concentration zone anomalies in pipelines that cannot be internally inspected. It is further accepted as a suitable technique for identification of weld locations and in confirming the positional accuracy and depth of pipeline assets for the purpose of excavation and for geospatial mapping amendments **[A]**. The full specification for the Speir Hunter SCT Technology is provided through the company web site **[C]**.

In the DA methodology, the first stage is to identify corrosion hotspots along a pipeline using portable hand-held equipment. A minimum of two excavations per year over a given pipeline is required, but often a pipeline operator will excavate all areas where the DA assessment identifies a high risk. Traditionally, this DA testing is undertaken using a direct current-voltage gradient evaluation to identify coating defects. However, in general, 90% of such identified defective coatings have not led to corrosion and hence have resulted in unnecessary excavation **[B]**.

The Speir Hunter SCT system has a probability-of-detection exceeding 90% for *metal* corrosion, and hence can be used to direct exploratory excavations to where there is an associated metal stress **[B]**. Typically, ten excavations would be undertaken per 10 km, with a single simple 10 m axial by 3–4 m deep excavation in a rural setting costing ~£20k **[D]**. This is significantly more expensive (up to £70k) in urban settings, owing to the excavation of infrastructure (e.g. roads, and above and below ground utilities), and their subsequent replacement **[A]**. The Speir Hunter SCT system therefore provides a significant cost benefit to operators through increasing the accuracy of the DA assessment (which limits the axial length of any excavation) and the number of excavation priorities. By reducing the number of physical invasive pipeline excavations, it also significantly lowers environmental risk, and infrastructural disruption.

Over this REF period, Speir Hunter has grown to ten full time employees, and now has international offices in Canada, the USA and China **[B]**. The Speir Hunter SCT system has

been used successfully to inspect oil and gas pipelines in all continents, except Antarctica; examples include **[B, E]**:

- GRTgaz inspected more than 300 km of pipeline in France.
- Petrochina commissioned a >200 km inspection in Inner Mongolia, with a joint venture company being established in Shanghai.
- In the UAE, Speir Hunter SCT was used to inspect 214 km of pipework in 2017 to provide a rigorous verification of the system's technical capabilities, and was followed by inspection of the remaining network in 2019, and a commission from Saudi Aramco.

Furthermore, in the USA and Canada, the Speir Hunter SCT system is being used on pipelines operated by Chevron, Colonial, Kinder Morgan, Enbridge, Trans Canada Energy, Husky and Conoco Phillips, in partnership with GE Inspection Services (GEIS) and ABB Group (following its purchase of GEIS) **[B]**. Following a successful verification of first trial results in this period, 265 km of pipeline will be inspected in Australia starting in 2021 **[B]**.

Corroboration of the typical financial benefit of using the Speir Hunter SCT technology compared with previous DA techniques is given by Rosen (UK) Limited, who provide a DA assessment service to pipeline operators **[D]**. Following an initial project with a client in Estonia, the client subsequently initiated a £1.5M three-year project to survey their entire non-piggable oil and gas pipeline network. The saving to the client is estimated to be £3M as a result of a 50% reduction in excavation requirements across a network of 30 cross-country pipelines of total length of around 200 km **[D].**

5. Sources to corroborate the impact (indicative maximum of 10 references)

[A] Letter from Senior Technical Engineer for Pipelines and AGI's Transmission, National Grid (UK), Cadwell Lane, Hitchin SG4 0SL, UK, 28th December 2020. (Sent as a phone scan due to COVID).

[B] Letter from Chief Executive, Speir Hunter Ltd, Windsor House, Long Bennington Business Park, Long Bennington, Newark NG233 5JR, 7th December 2020

[C] Speir Hunter's website (https://www.speirhunter.co.uk/), official brochures available at (https://www.speirhunter.co.uk/online-brochures2), IP position https://www.speirhunter.co.uk/ip-protection).

[D] Letter from Head of Materials and Corrosion, Rosen (UK) Ltd, Floor 2 Q5, Quorum Business Park, Benton Lane, Newcastle upon Tyne NE12 8BS, 10th December 2020.

[E] https://www.speirhunter.co.uk/project-portfolio