SCT

Stress
Concentration
Tomography

WHITE PAPER

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1 EXECUTIVE SUMMARY

There are over 3 million miles of unpiggable pipelines worldwide. Monitoring the integrity of these ageing ferromagnetic pipelines poses a significant problem for pipeline operators. The costs of converting the pipeline for In-Line Inspection (ILI), considered to be the gold standard of pipeline inspection, are very high and in many cases this conversion process is not possible due to physical limitations of the pipeline. The alternative for integrity managers is to apply one or more of the inspection methods used in the External Corrosion Direct Assessment (ECDA) process. However, the ECDA process is lengthier than Pipeline Internal Gauge (PIG) inspection, is often more expensive when excavations are costed into the total price, faces more technical limitations and delivers less in-depth information on the pipeline wall condition than does an ILI inspection.

Developed by Speir Hunter Ltd. in collaboration with the University of Leeds, SCT™ is a screening tool that can be deployed with ILI and ECDA processes to optimise the accuracy of results and to dramatically reduce inspection costs. It is considered by some well respected engineers in the industry to potentially offer a comprehensive solution for the inspection of unpiggable pipelines thereby eliminating the incentive to convert an unpiggable line for ILI inspection as well as to completely replace the ECDA process. This is why such notable figures have described SCT™ as a potential '*game changing technology*.'

Recently branded by the industry as Large Standoff Magnetometry (LSM), SCT™ is a truly original method of non-contact inspection that assesses the integrity of a pipeline's wall condition through the analysis of remotely collected magnetic data. SCT™ is non-invasive: the inspection does not require a change in any of the operating parameters of the pipeline such as pressure or flow rates. Furthermore, there is no need to place sensors on the pipeline to amplify the magnetic field or to conduct an excavation after inspection to calibrate results. The pipeline remains in its normal operating condition throughout the SCT™ inspection process.

During SCT™ inspection, the field operator walks directly above the pipeline carrying an array of sensitive magnetometers that remotely collects the pipeline's natural magnetic field data down to nano-tesla level. Survey-grade GNSS equipment tracks the movement of the operator stamping cm accurate locational positioning information on the magnetic data 40 times a second as it is collected in real-time. This data is then downloaded into software that analyses the magnetic signatures detecting and quantifying all areas of abnormal localized stress in the pipeline wall.

SCT™ detects and estimates the stress caused by all types of metallurgical and mechanical defects (including Stress Corrosion Cracking (SCC) and weld defects) in the pipeline wall, irrespective of clock position and whether or not the defect is internal or external to the pipe. It is also the only inspection technology in the world that can concurrently identify the stress-levels of defects in a pipe whilst simultaneously mapping the pipeline's depth of burial and lateral position. SCT™'s 3D Mapping feature provides the lateral position and depth of cover of the pipeline to sub-meter accuracy. This information can be used to detect geotechnical hazards, such as underground earth movement, before they cause pipeline failure and to identify segments of the pipeline where soil erosion has led to a dangerously shallow depth of cover.

SCT™'s deliverables also anticipate future regulatory demands on pipeline integrity management. For example, it can be used to detect the location of casings, changes in wall thickness and diameter and wrinkle bends. Stuck PIGs and illegal hot tapping can also be reported and all these aforementioned characteristics can be delivered from a single survey using the same data.

In 2015 SCT™ demonstrated a repeatability of detection exceeding 80% with sub metre accuracy at a Pipeline Research Council International (PRCI) trial in Texas. In 2016 Speir Hunter was invited to talks to establish the formulation of a common SCT™ European standard. These talks are continuing in 2017 with an ISO committee meeting in London. Looking to the future, developing SCT™ for marinisation and drone-deployment are already under serious discussion. It is on this optimistic note of accelerating development and growth that Speir Hunter Ltd. introduces you to Stress Concentration Tomography.

Sincerely,

Speir Hunter Chief Executive Officer
Paul Jarram

Figure 1 UNISCAN™ deployed in the USA on a small-diameter line.

Figure 2 UNISCAN™ scanner deployed in China on transmission line illustrating uninterrupted data collection at normal walking speed.

2 METHOD STATEMENT

2.1 FUNDAMENTAL PRINCIPLES

SCT™ provides high-resolution information on the wall condition of an underground pipeline. It detects all mechanical and metallurgical defects such as cracks, internal and external corrosion, and pipeline deformations caused by land movement. It also collects real-time data of the pipeline's depth of burial underground.

During an SCT™ inspection, a technician carries the UNISCAN™ Scanner directly over the center of the pipeline. The scanner passively collects magnetic data of the pipeline underground; there is no need to induce energy into the pipeline, turn off CP systems, or change the pipeline operating pressure during inspection.

Upon completion of the field survey, Speir Hunter's patented software analyses the pipeline magnetic data using complex algorithms that can decipher the mathematical relationship between material stress and magnetisation. The software reports the location of all abnormal zones of localised stress in the pipeline wall material by analysing changes in the pipeline magnetic data. We call such areas 'Stress Concentration Zones' (SCZs).

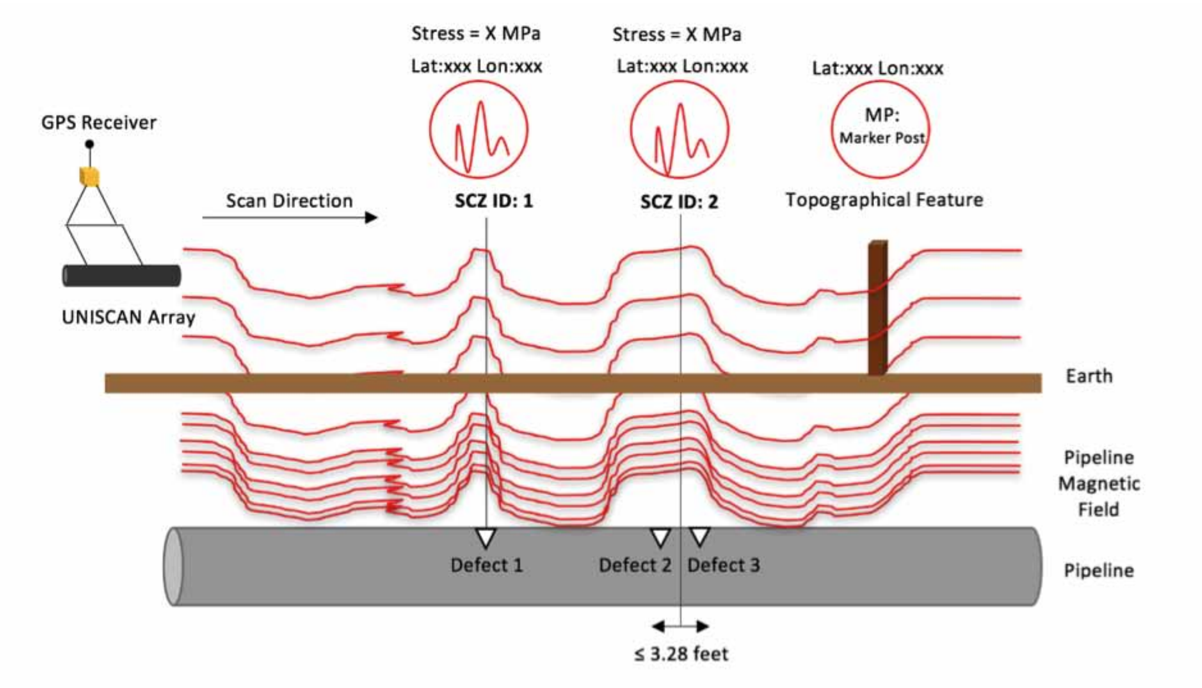


Figure 3 SCT™ (Stress Concentration Tomography) collects data on the pipeline's latent magnetic field remotely in order to assess the pipeline wall condition.

HOW SCT™ WORKS

SCT™ is based on the science of stress-magnetisation. Whenever there is wall thickness loss in a pipeline wall, there will be an increase in stress. There will also be a change in the pipeline's magnetic domains. SCT™ can identify abnormalities in the pipeline's magnetic field and work backwards from this to infer an exact stress-value at that point in the pipeline. Because any mechanical or metallurgical defect will lead to localised stress zones in the pipeline wall, SCT™ can detect any and all defects that affect buried pipelines.

Observation 1: There is a predictable relationship between stress and magnetization in all ferromagnetic materials.

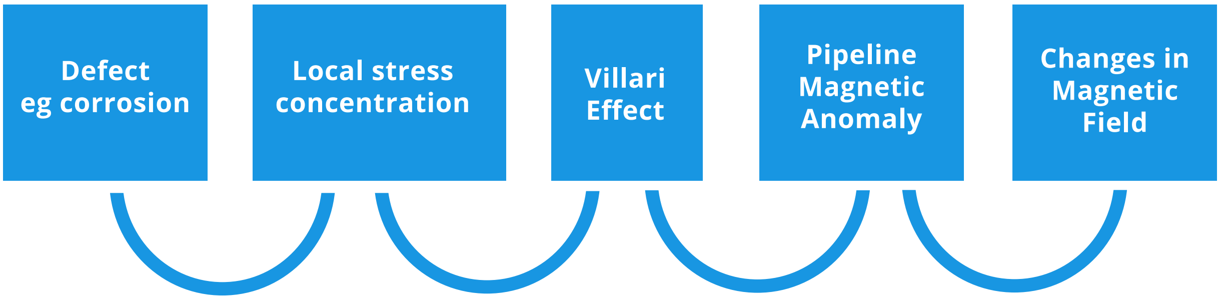


Figure 4 Ferromagnetic materials respond to localised stress by behaving in accordance with the Villari Effect upon which SCT™ has been built.

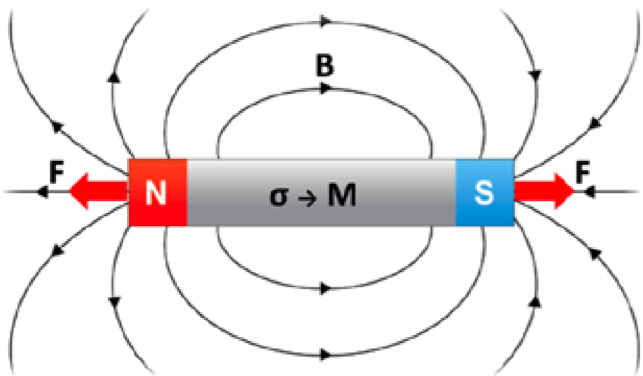


Figure 5 The Villari Effect: There is a predictable mathematical relationship between changes in the ferromagnetic material stress and changes in the material's magnetic field.

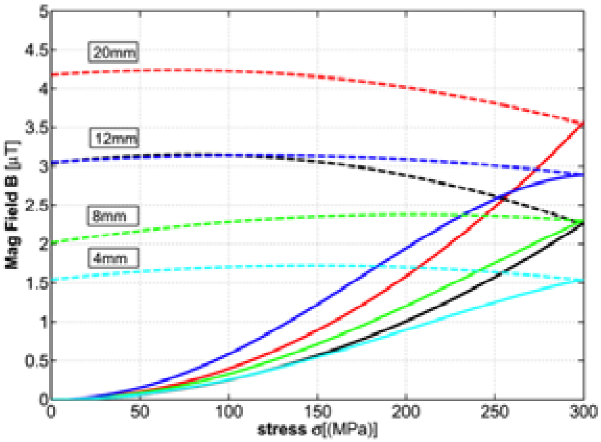
Observation 2: Once you pressurise a pipeline, it becomes magnetic. In SCT™, this phenomenon is called the magnetic saturation of the pipeline.

Once a pipeline has been pressurised, the induced hoop-stress on the pipeline causes its magnetic domains to re-align. This creates a permanent magnetic field that remains at a predictable constant value even if the pipeline's operating pressure decreases.

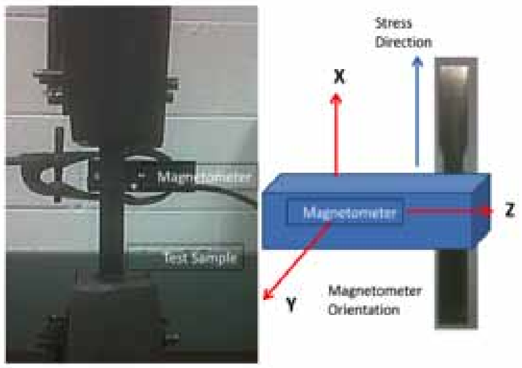
SCT™ algorithms measure abnormalities in this predictable background magnetic field of the pipe, and then continue to characterise the magnetic signatures in order to infer the material stress-value at that point.

Solving the inverse problem of magnetisation–stress resolution
S. G. H. Staples, C. Vo, D. M. J. Cowell, S. Freear, C. Ives et al.

Citation: J. Appl. Phys. 113, 133905 (2013); doi: 10.1063/1.4799049



Curve fit of stress–magnetisation, showing variation of magnetic memory with sample width.

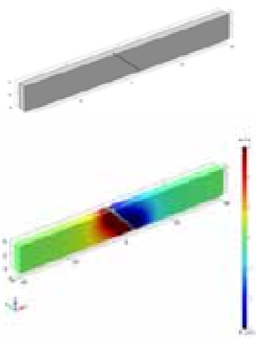


Subjecting the 20 mm sample to tensile stress.

Figure 6 Extracts from an article published by Speir Hunter's researchers describing the relationship between stress and magnetisation. A controlled experiment was conducted in a lab in which a magnetometer was placed near to a sample piece of metal. Stress was applied to the metal, and then steadily removed again. The function on the left shows the effect of magnetic hysteresis, where the stress-induced magnetism of the metal remains constant despite the absence of stress.

Observation 3: Any wall thickness loss or deformation in the pipeline will cause an increase in localized stress in the pipeline wall. This will create an anomaly in the pipeline magnetic field.

Each anomaly in the magnetic field has a unique signature. SCT's algorithms identify these areas. They then calculate the absolute stress-value occurring at that point of localised stress in the pipeline wall.



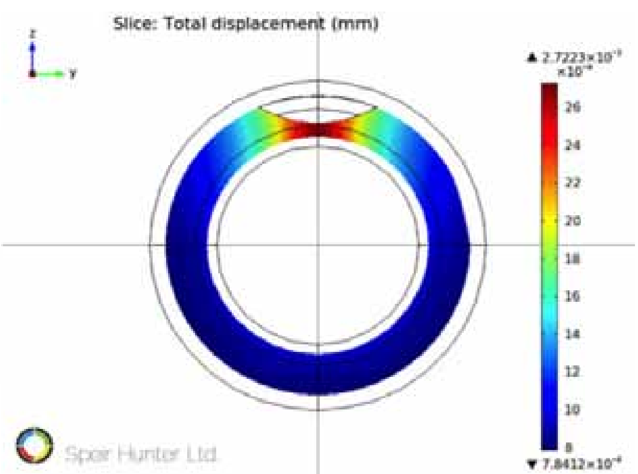


Figure 6 (continued)

2.2 EQUIPMENT

SCT™ is a wholly digitalised method of inspection comprised of a magnetic data collection
and analytical processes in which patented hardware and software are used in each respective stage. UNISCAN™ is the term assigned to the hardware which is used to collect magnetic data and UNISCAN Tools™ is the software which is used to analyse the collected data and to generate pipeline condition and mapping reports.

UNISCAN™

UNISCAN™ is essentially comprised of a magnetic data collection unit with a GNSS time stamp system attached. It carries an array of magnetometers that collect the pipeline's magnetic field in multiple dimensions and an onboard data logger that provides an LED display unit for the field operator to use as he walks along the axis of the pipe. GNSS geo co-ordinates are stamped on the magnetic data at a rate of 40Hz and all data is then stored in a military grade USB stick which can hold 200km of data per survey. The UNISCAN™ device is constructed of a lightweight carbon-fibre frame. It is easily transported and constructed on-site, is durable under harsh weather conditions such as rain, snow or high temperatures and is easy to operate. It weighs less than 7kg, is carried by a single field operator and operates at walking speed. With a team of two in optimal conditions up to 10km of pipe can be inspected per-day.

UNISCAN™ uses survey-grade GNSS hardware to define the position of the scanner and detected SCZs. This is comprised of a stand-alone base station with a radio connection to a dynamic receiver attached to the UNISCAN™ frame. Under a clear sky-view, the geometric centre of SCZs are detected and reported to sub metre accuracy.

Figure 7 UNISCAN™ deployed on distribution lines at a gas facility in the United States.

The GNSS system is used in three ways. Firstly, it is used to stamp locational data onto magnetic data in real time. As the UNISCAN™ operator walks along the pipeline axis GNSS data is stamped onto magnetic data at a rate of 40 times per second. This magnetic-locational data is then stored on the onboard USB stick and is uploaded to a PC upon completion of the magnetic survey.

Secondly, it is used to conduct topographical surveys of above-ground objects along the pipeline route prior to SCT™ inspection. During the data analysis process these objects are correlated with magnetic data to assist in the identification of areas where magnetic data may have been compromised by above-ground metallic objects. If this is confirmed the geo co-ordinates of affected segments are defined in the report. They are also used to establish reference points to aid excavations.

Thirdly, the GNSS system stakeout function is used to guide excavation teams to sub metre accuracy to the dig site location.

UNISCAN TOOLS™

UNISCAN Tools™ is a software package that processes data using a combination of complex algorithms to detect SCZs, locate their position, estimate the stress of each SCZ, filter out common sources of magnetic interference such as overhead power lines, determine the pipeline's depth of cover, and to generate a 3 dimensional map of the pipeline route. The software's only input is the magnetic and positional data collected by UNISCAN™, with nominal hoop stress and material SMYS (Specified Minimum Yield Strength) of the pipeline as provided by the client, so that a reference is generated in the report.

UNISCAN Tools™ can also differentiate between underground metallic objects and defects on a pipeline and, uniquely for an inspection system, generates a 3 dimensional map of the pipeline route (including depth of cover). All of this is achieved using the same datasets collected by UNISCAN.

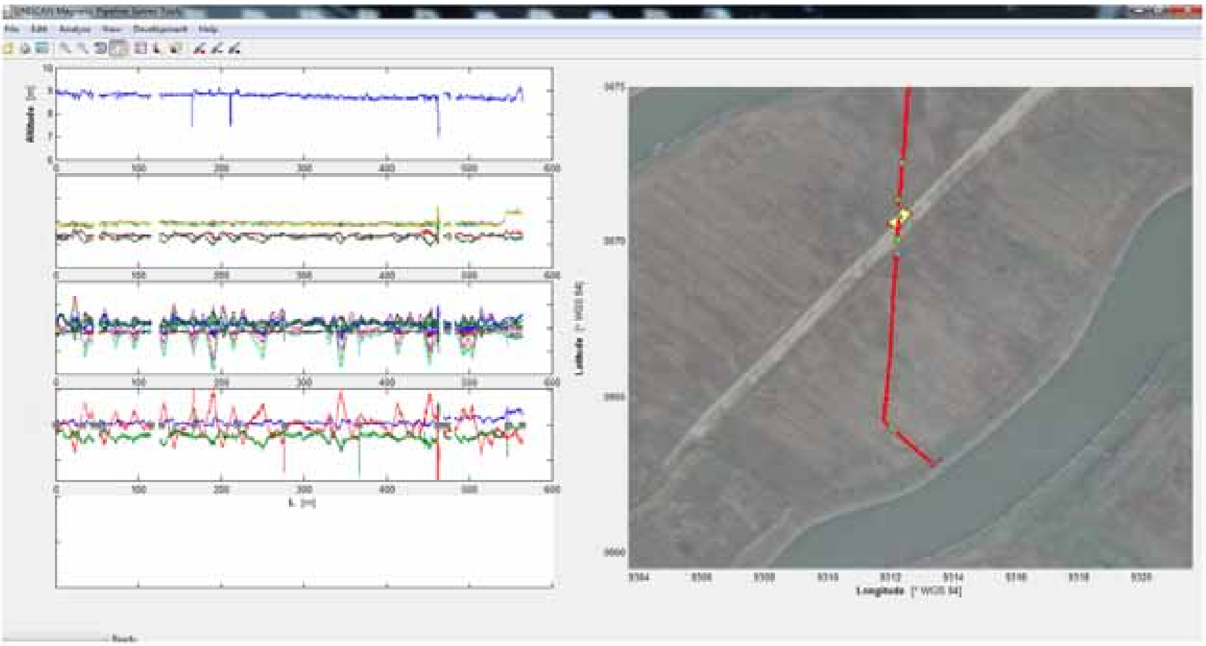


Figure 8 UNISCAN Tools™ automatically generates preliminary results. In this way a client can be notified very early if a section of pipe is found to be in a serious condition and which potentially requires urgent action. Geo co-ordinates have been modified to protect client confidentiality.

Figure 9 SCT™ can detect defects on and near to girth welds.

2.3 PROCESS WORK FLOW

When a pipeline operator formally requests a proposal from Speir Hunter the following process workflow is launched. Note there no hidden extras such as changes to operational parameters or excavation requirements and the price is lower than high resolution tools offered by ILI companies and also lower than ECDA when the costs of excavations are taken into account.

Stage 1: Enquiry

Client contacts Speir Hunter about interest in deploying SCT™ inspection on their pipeline. Speir Hunter assesses the technical feasibility of the pipeline by sending out a technical questionnaire for the client to fill out, sign, and return.

Stage 2: Pre-Survey Analysis

If the pipeline is technically suitable for SCT™ inspection a pre-inspection survey is conducted along the route of the proposed survey to assess the suitability of the terrain for an SCT™ inspection. This may be conducted on site or a desktop review using photographs and videos supplied by the pipe operator. Obstacles on the survey route are reported to the operator with a request that where possible they be cleared prior to the arrival of the inspection team.

Stage 4: SCT™ Magnetic Data Collection & Above-Ground Topographical Feature Mapping

A two man team is mobilised to conduct the SCT™ survey. The pipeline route is marked out using a pipe detector and significant above-ground topographical features are recorded using the GNSS data logger. A single technician collects magnetic data of the pipeline by walking directly above the pipeline along the survey route carrying UNISCAN™. Data is collected at walking speed and is stored on an onboard USB stick.

Stage 5: Data Analysis and Report Production

Magnetic data is uploaded to a data analysis centre in the UK immediately after the survey is completed where analysts generate preliminary results using UNISCAN Tools™ and then compile a Final Report that contains the results specified by the line operator. This may be comprehensive integrity information of the client’s pipeline, 3 dimensional mapping,or the location of specific features such as wrinkle bends. Speir Hunter provides technical support after the completion of the project if the client needs help interpreting the results in the Final Report.

Stage 6: Repair & Verification

If the client decides to return to site to excavate for repair or to verify results using direct assessment high-resolution tools, SCT™’s GNSS positiozning system can facilitate the process by using its stakeout function which provides sub-meter positional accuracy.

Figure 10 Technicians assembling UNISCAN™. The device is portable and rapidly assembled onsite. Construction takes between 10-15 minutes.

Figure 11 UNISCAN™ deployed on an underground pipeline whose route has already been marked out by a pipe locater.

Figure 12 Technicians set up the Base Station to receive signals from GPS and GLONASS satellites and which broadcasts its position to the GNSS receiver attached to the rear of the UNISCAN™ frame.

Figures 13 Electronic loggingof location of topographical features above the pipeline route using UNISCAN's™ GNSS system.

Figure 14 SCT™'s GNSS stakeout function is used to locate thepredicted position of internal corrosion whilst returning to site during an excavation.

3 SCT™ DELIVERABLES

Any increase in localised stress generates a reorientation of magnetic domains in the SCZ (Stress Concentration Zone). These reoriented magnetic domains then appear as an anomaly in the pipeline's magnetic field. SCT detects these anomalies in the presence of any metallurgical or mechanical defect that causes an increases in localised stress, irrespective of the clock position.

SCT™ does not currently categorize defect types (though this capability is at the present time being developed). However, it can distinguish between signals generated by defects with those by casings or changes in a pipeline wall thickness and/or diameter.. The magnitude of stress in the SCZ is reported and compared with nominal operating hoop stress and material SMYS and where specified by the customer, SCT™ presents a 3 dimensional map of the pipeline route reporting its lateral position to within +/-10cm and depth of cover to a +/-5% of actual depth. SCT™ is the only technology in the world that can inspect and map a pipeline at the same time.

SCT™ is a completely remote form of inspection and is not therefore restricted by pipeline configurations, tight turns or valves. Moreover because it is completely non-invasive there is no need to change pipeline operating parameters. An SCT™ inspection

3.1 KEY CAPABILITIES

SCT™ reports deliver the following information:

- High precision definition of location of SCZs and magnitude of stress caused by:
    - stress corrosion cracking (SCC).
    - weld defects.
    - stresses caused by ground movements, e.g. subsidence, landslip and washouts.
    - internal and external corrosion and metallurgical defects irrespective of clock position.
- Detects the location of changes in pipeline wall thickness, diameter, and beginnings and endings of casings.
- Detects stuck PIGs and illegal hot tapping.
- Generates a high precision 3 dimensional map of the pipeline route.
- High precision location of girth welds over short lengths (to assist in identifying excavation locations).

Key Commercial Benefits of SCT™

- Does not interrupt pipeline operations.
- No minimum or maximum operating pressure required,
- No change in flow rates required.
- No lost production during inspection.
- Does not require the CP current to be switched off.
- Does not require excavation for direct assessment of pipeline or to calibrate results.
- Does not need the use of direct contact sensors or amplification of the pipeline magnetic field prior to or during inspection.

Key Metrics

SCT™ has demonstrated its consistent accuracy through field projects showing a repeatability of detection to cm accuracy and estimation of stress repeatability within +/-10% of modelled predictions. The key metrics of SCT™'s capabilities at its current stage of development are summarised below and expanded in the technical specification at the end of this document.

1. Probablity of Detection of SCZs: Not less than 80% of verified inspection locations with a confidence level of 95% in conditions where no magnetic interference is experienced.

2. Locational Accuracy: <1m (axial); +/-10cm (lateral).

3. Pipeline Depth: ± 5% of the actual depth to a confidence level of 95%.

Girth Weld Detection

Speir Hunter is developing an experimental girth weld detection algorithm that can provide the above-ground location of all girth welds on a pipeline accurate to ±2meters.

This could provide huge-value to ILI operations in which chainage distances can be offset by up to 60-80 meters, depending on the complexity of the environment.

SCT™'s girth weld detection algorithm could save substantial sums for intergrity departments by optimising excavation accuracy of ILI results.

3D Mapping features

SCT™ also provides clear charts and diagrams showing the pipeline's lateral position and its depth of cover. This information is particularly useful for identifying pipeline movement in geohazardous areas before they cause failure. SCT™ maps can be used to detect and report pipeline buckling due to earth movement but segments with shallow depth of cover reported in regions of soil erosion can also be used to facilitate actions which will reduce the chances of a pipeline strike.

Figure 15 MPI confirms SCC microcracks detected by SCT™.

Figure 16 & 17 Lateral deformation of a pair of parallel pipelines due to underground earth movement detected by SCT™'s 3D mapping functionality.

Figure 18 A GIS overlay of SCT and DCVG/CIPS results. SCT data is easily integrated into the datasets of both DCVG/CIPS and ILI results to allow intuitive cross-comparison of data.

3.2 OPTIMAL CONDITIONS AND LIMITATIONS

The fundamental requirement of SCT™ is that the target pipeline must be constructed from a ferromagnetic material. If not, SCT cannot be used. Additional factors that are considered when assessing if a pipeline is a suitable candidate for SCT™ inspection include environmental conditions along the pipeline route and its operating parameters.

Environmental Limitations

- *Above-ground physical objects and geographical features* that prevent the UNISCAN™ operator from walking above the pipeline to collect data.
    - Examples: Buildings, walls, fences, steel overhanging structures, stairs, wide rivers, swamps.
    - Solution: If the obstructing object cannot be moved or resolved there is no inspection solution but the Final Report clearly explains why no magnetic data was collected at specific segments of the pipeline survey and defines their locations.
- *Reinforced concrete* can affect stress estimation results.
    - Example: SCT™ can collect magnetic data from pipelines buried under reinforced concrete but the effect of the rebar may adversely affect the accuracy of defect detection and stress estimation results.
    - Solution: More time is spent during the data analysis stage to manually refine auto generated SCT™ results in sections of survey under reinforced concrete.
- *A restricted sky-view* can impact the GNSS signal accuracy and increase the length of time required to inspect the pipe.
    - Example: Pipeline routes that run through urban areas with many high buildings or dense forests where the canopy restricts the sky view.
    - Solution: If obstructions to sky-view cannot be cleared, then a combination of the deployment of a prism and laser in the field and manual analysis of GNSS data can restore positional data to the specified standard.

It is important to note that anomalies in the pipeline's magnetic field caused by underground metallic objects such as debris eg discarded welding rods, are identified by UNISCAN Tools™ in the data analysis process and do not constitute a limitation to an SCT™ inspection. Such features are predicted as probably present.

Pipeline Physical Configuration Limitations

The technical parameters that affect the accuracy of an SCT™ inspection are summarised below. It is important to note that they are not absolute limitations and that some desired thresholds can be crossed.

However doing so may require manual intervention when interpretating data from affected areas of the magnetic survey. The crossing of these thresholds does not automatically constitute an absolute limitation to an SCT™ inspection.

- *Parallel pipes* can cause interference of data collected from the target pipe.
    - o Desired threshold: If the outer wall of one pipeline in a pair of parallel pipes is greater than 0.5m in distance from the outboard magnetometer nearest to it then there is no magnetic interference. Beyond this limit it might be difficult to distinguish from which pipe detected SCZs originate ie from a defect in the target pipe or the parallel pipe.
- *Pipeline depth of burial* can affect the strength of the magnetic field of a pipeline.
    - o Desired Threshold: If the distance of the centre of the pipe to UNISCAN is no greater than 12x the diameter of the pipeline, then stress estimation results are optimal. Beyond this limit, the accuracy of stress estimations might be adveresely affected.
- *Pipeline diameter* can affect the strength of the magnetic field of a pipeline.
    - o Desired threshold: If the pipeline diameter is >150mm (6 inch) then defect detection and stress estimation results are reliable. Beyond this limit the accuracy of stress estimations might be adversely affected though the detection of defects is less affected.
- *The Magnetic Memory (MM) Threshold*. A hoop stress of 65 MPa should be or have been experienced by the pipeline during inspection otherwise the SCT™z stress estimation results will be less accurate. Once the MM threshold has been reached, the magnetic response to increased stress caused by defects effectively becomes a permanent magnet. In this condition the behaviour of the localised magnet is predictable and is effectively independent from operating pressure.
    - o Desired Threshold: *I*f the pipeline has reached a hoop stress of 65 MPa at least once in its operational history then it has passed the magnetic memory threshold. The hoop stress calculation is based on Barlow's equation: PD/2T = (Operating Pressure x Pipe diameter) / (2 x Pipe Wall thickness).

Limitation caused by previous inspections using In Line Magnetic Flux Inspection (MFL)

- MFL destroys the self magnetic flux leakage (MFL) that is detected in SCT™ and therefore a period of time is required following an MFL inspection for the induced magnetism to decay and SMFL to become re-established. These conditions are usually reached 12 months following an MFL inspection. An SCT™ survey to identify the location of girth welds would not normally be recommended to take place earlier than 12 months following MFL inspection.

3.3 REPORT FORMAT

SCT™ Final Reports are consistent with international standards and contain directly actionable data that allow integrity managers to make informed decisions concerning the integrity of their pipeline. SCT™ reports the magnitude of localised hoop stress at each SCZ, together with its location, and presents it as a percentage of material specified minimum yield strength (SMYS). This figure is banded in accordance with the safe values specified in ASME B31G which defines maximum limits of hoop stress according to population proximity and density. Using this data, integrity engineers can decide whether further action is needed on the pipeline eg repair or further investigation by direct assessment at specified sites using standard high resolution tools.

The Final Report also contains conclusions and recommendations, a detailed record of technical pipeline information supplied by the client and a photographic record of typical and significant features along the pipeline route. Although the formal written report may take typically 4 weeks to prepare and submit following demobilization, it is possible to process data on a daily basis to identify particularly hazardous SCZs.

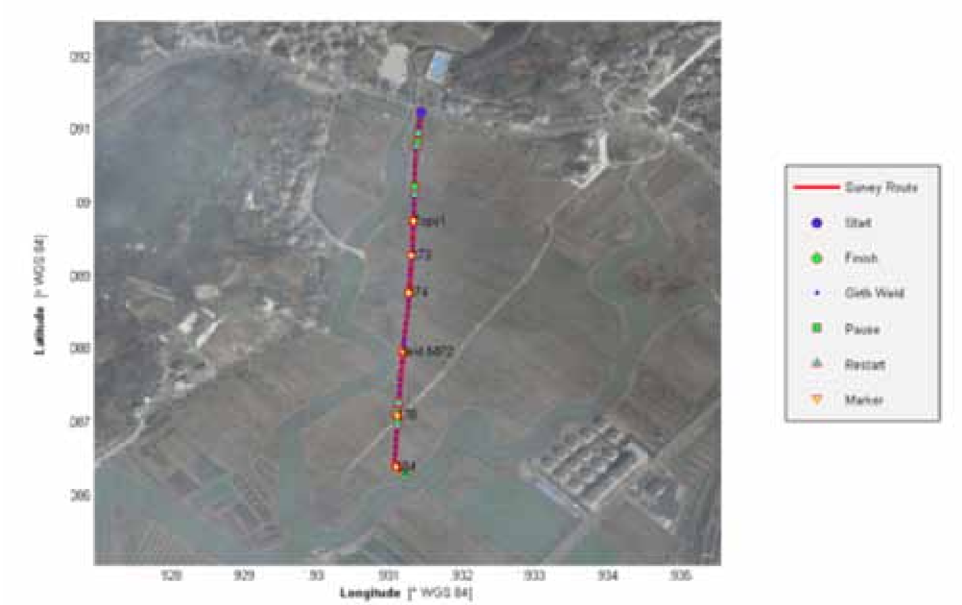


Figure 19 SCT™'s girth weld detection algorithm mapped onto the pipeline route. The girth welds are represented by blue dots, and are mapped onto the pipeline route (red line). Above ground marker posts are represented by the yellow triangles. GNSS co-ordinates have been modified to protect client confidentiality.

SCZ ID	Distance [m]	Latitude [WGS84]	Longitude [WGS84]	Altitude [m WGS84]	Estimated Stress [MPa]	Stress in SCZ as % SMYS
59	0.53	XXXXX	XXXXX	185.42	358.190	79.59
106	1.57	XXXXX	XXXXX	185.41	378.243	84.05
152	2.77	XXXXX	XXXXX	185.41	359.530	79.89
283	6.51	XXXXX	XXXXX	185.26	66.753	14.83
323	7.67	XXXXX	XXXXX	185.29	70.373	15.63
723	17.00	XXXXX	XXXXX	185.09	393.897	87.53
1185	27.56	XXXXX	XXXXX	185.45	92.822	20.62

Figure 20 An Anomaly Table detailing a unique ID for each SCZ, the distance of the SCZ from the start of the survey, the precise GNSS co-ordinates of the SCZ, and their stress estimations both in MPa and as a percentage of the pipeline's material SMYS. Using the SCZ ID, it is possible to cross reference a visual representation (see below) of its position with its properties as well as its position along the survey route as seen in the Survey Map (see next page). GNSS co-ordinates have beenremoved to protect client confidentiality

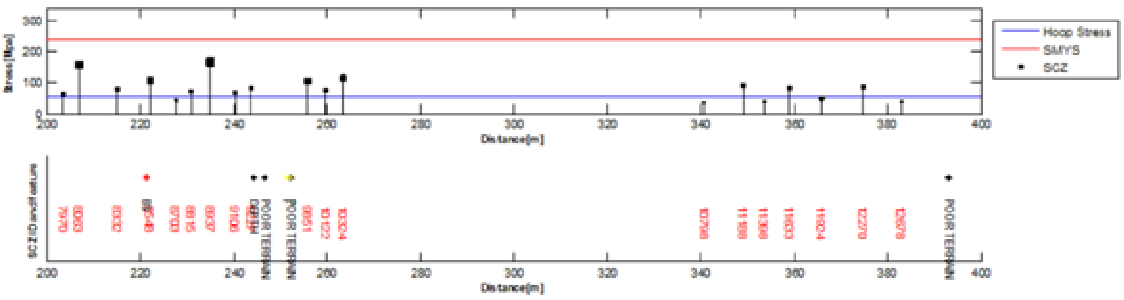


Figure 21 Strip charts providing a visualised view of the location of all SCZs on the survey route together with their unique ID number, estimated stress value and relation to above ground topographical features. In the top chart, the blue line represents the pipeline's nominal hoop stress and the red line represents the nominal SMYS of the pipeline material grade. Both figures are calculated using technical information supplied by the client in the pre-survey questionnaire. Each black square is an SCZ and its unique ID can be found in the bottom chart which also records salient above-ground topographical features.

Figure 22 Survey Map showing a portion of the pipeline route inspected by SCT™. The red line shows the survey route, the black dots represent SCZs, the red text by each SCZ is its unique ID which can be cross referenced in both the anaomaly table and strip charts. GNSS co-ordinates have been removed to protect client confidentiality.

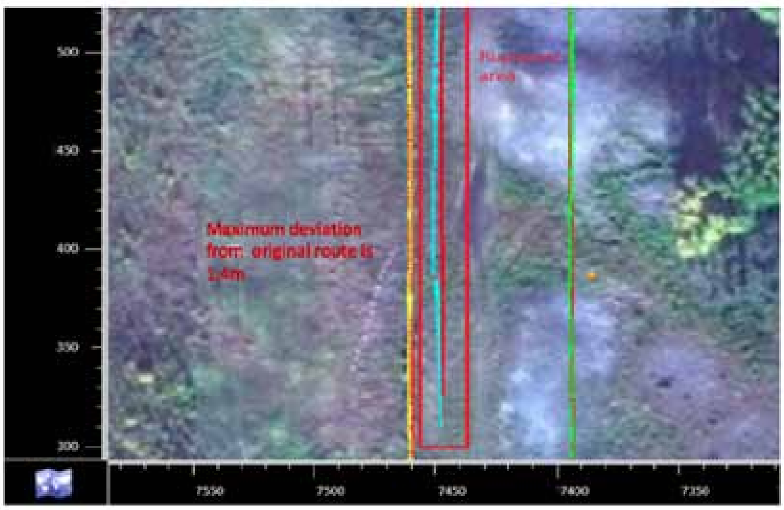


Figure 23 SCT™ displays the lateral deformation of a pipeline (blue line). This deflection reached a maximum deviation of 1.4m from the expected pipe route and occurred in an area of known land slippage. This deformation occurred within the 1440-1480m range of the survey. GNSS co-ordinates have been modified to protect client confidentiality.

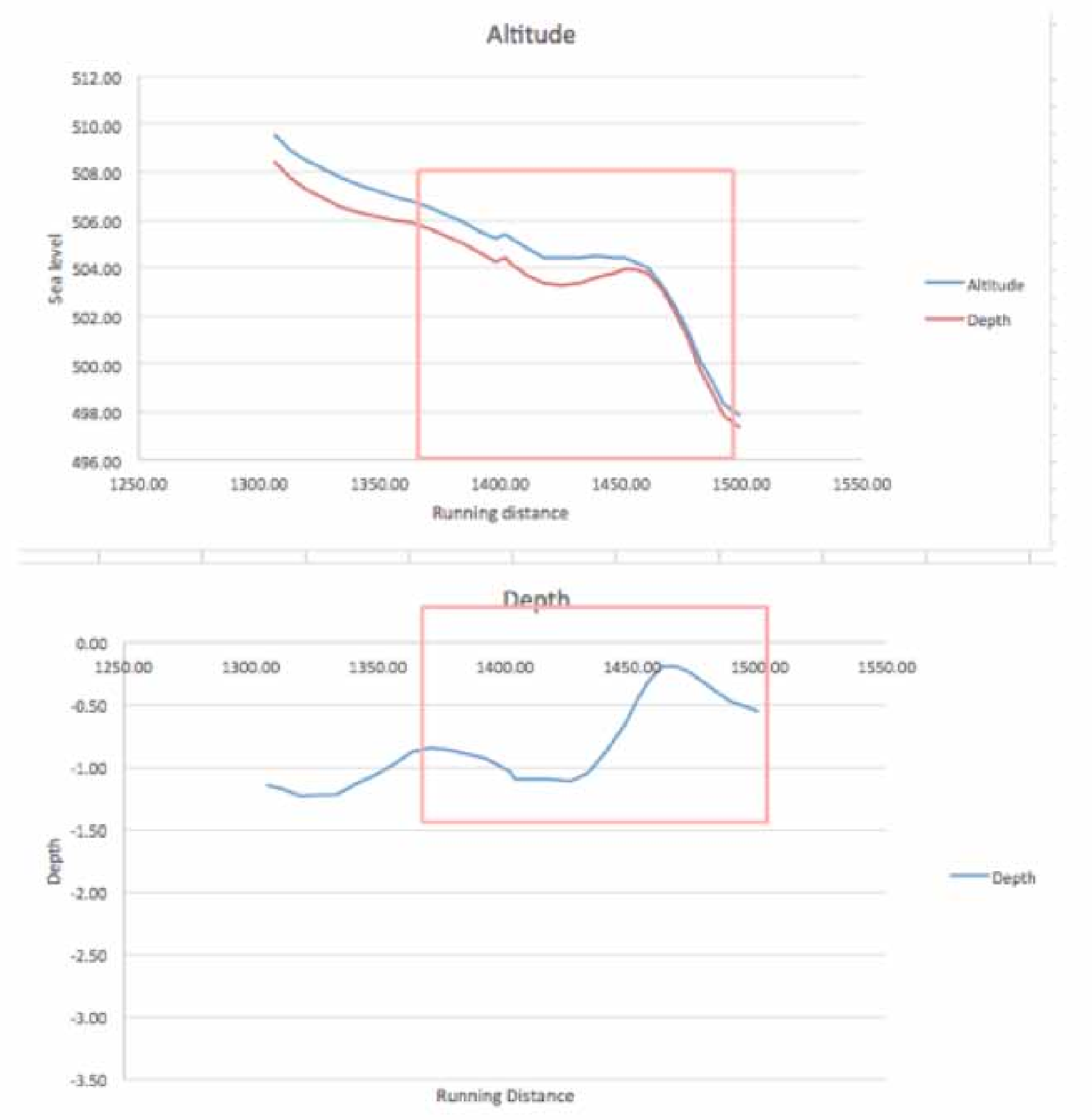


Figure 24 SCT™'s depth of burial algorithm identifies pipeline buckling in the same section of the same pipeline featured in figure 19. In the top chart the blue line shows the altitude of the ground level and the red line shows the altitude of the pipeline itself. In the 1440-1480m section, the pipeline bends upward to a depth of cover of less than 0.5m as is shown in the bottom chart.

4 COMMERCIAL BENEFITS OF SCT™

4.1 COMMERCIAL BENEFITS OF USING SCT™ AS A SCREENING TOOL IN THE ECDA PROCESS

The most widely used method of assessing the integrity of unpiggable pipelines is External Corrosion Direct Assessment (ECDA). This four-step procedure requires a pre-assessment which involves the collection and evaluation of historical data and pipeline characteristics, indirect assessment, direct examination and post assessment with direct and indirect assessment using one or more of the following techniques:

Indirect Assessment Methods

Close Interval Survey (CIS)
Direct Current Voltage Gradient (DCVG)
Alternating Current Voltage Gradient (ACVG)
Pipeline Current Mapper (PCM)
C-Scan
Soil Resistivity

Direct Examination

Coating conditions
Corrosion mapping and data collection
Pipe defects and metal loss
Remaining strength of the pipe
Soil type, pH levels, depth
Cathodic protection evaluation

This is followed by scheduling an anomaly verification dig plan and once this is completed all data is processed leading to the issue of a final report.

Technical and Commercial Benefits of SCT™ over the ECDA Process

Although well established, the ECDA process faces two key weaknesses:

- Firstly, it can only report on the condition of pipe metal it has inspected using direct contact NDT techniques. Without these excavations, it provides the probability alone of corrosion – and excavations are expensive.

- Secondly, it’s projections can be made by considering environmental factors and the condition of the CP system but this is a costly and lengthy process.

SCT™ inspects pipelines at a faster rate than the ECDA process as whole. Provided the pipeline route has been marked out before the inspection team arrives on site, up to 10kms per day per team of 2 people can be inspected. The multiple inspections used by ECDA make assessment considerably slower. In SCT™, two technicians arrive on site, set up the GNSS system, walk the pipeline route noting electronically the geo co-ordinates of all significant topographic features then return to the start point, assemble the scanner and walk continuously along the pipeline route. The two GNSS receivers have a range of 2.5 metres allowing a 5km inspection in a single pass if the base station is located 2.5 km downstream from the start point. Range can be doubled, where required, using a more powerful antenna.

Costs per mile (1.6km)

Interstate Natural Natural Gas Association of America	$15k
American Gas Association (members estimate)	$7k – $8k not including excavations
American Gas Association (members estimate)	$2.5k - $250k excavation costs
American Gas Association (members estimate)	$40k for typical transmission line
PG&E report an average cost to perform ECDA	$29k

Figure 25 Table detailing the typical cost of ECDA based on data collected by the US Department of Trade Regulatory Evaluation of Pipeline Integrity Management published in 2001.

4.2 ADVANTAGES OF SCT™ OVER COMPETITOR LSM TECHNOLOGIES

MTM is a magnetometry technique which claims to report the condition of pipelines in similar detail to those reports obtained from ILI inspections. Feedback from within the industry shows that after 16 years of commercialisation the integrity of results varies dramatically. Positioning on earth uses a cotton thread attached to an onboard odometer in conjunction with a low cost hand held Garmin GPS meter. Magnetic data is stored in magnetic memory blocks and complex computer generated charts are analysed by eye by technicians.

Key Technical and Commercial Benefits of SCT™ over MTM

- SCT™ provides more comprehensive data than MTM. It is the only inspection technique in the world which can provide 3D mapping of the pipeline (including depth of cover and lateral position of pipe) in addition to a pipeline wall condition report. It can also report girth weld positions, the location of wrinkle bends, beginning and ending of casings and changes in pipeline wall thickness and diameter.

- The rate of inspection in SCT™ is faster than in MTM. The stop – start nature of MTM caused by the use of winding out a thread from an onboard odometer is a prime limitation in terms of speed of inspection.

- SCT™ is developing a girth weld detecgtion algorithm. Moreover, it can already differentiate between signals caused by defects and those caused by changes in a pipeline wall thickness or diameter..

- Unlike MTM, SCT™ quantifies the stress in SCZs in an absolute measurement automatically using software algorithms. Our competitors report the relative severity of stress in SCZs and use manual data analysis to pick out the details. This is a major design flaw in the technology, not only because it exponentially increases the chances of human error on longer sections of data but also because it can conceal the true severity of a defect especially if the SCZs on a pipeline are severe and the range between each stress zone is small.

- SCT™ reports pipeline wall condition data transparently and with a format consistent with international standards such as ASME B31G. Our main competitor, however, maintains a private ‘traffic light’ system that does not explain to customers the criteria used to evaluate the severity of a defect. Moreover, whereas SCT™ clearly demonstrates in reports areas where magnetic interference has rendered the results less accurate or where obstructions prevented data collection, our competitors do not do so. Failing to do so misleads the customer and increases the chances of pipeline failure. Unlike our competitors, SCT™ has an onboard display unit that tells its operator in real-time whether or not there is a problem with magnetic data collection. Without this, operators are at risk of wasting entire days collecting invalid data thereby increasing the time and costs of the survey.

4.3 Pricing and Key Benefits of Long-Term Use of SCT™

There are no additional costs incurred when commissioning SCT™ inspection. Proposals quote a fixed mobilisation charge, a fixed field inspection charge and a fixed analytical and Final Report charge. There no hidden extras and the price quoted is less than that charged for the use of "gold standard" high resolution tools offered by ILI companies. This leads to significant cost savings, as will be illustrated in the following case studies.

Case Study 1: The Costs of Converting Unpiggable to Piggable Lines

SCT™ can be used as a cost-saving long-term solution for maintaining the integrity of unpiggable pipelines. SCT™ reports the magnitude of localised hoop stress at each stress concentration zone (SCZ). It also presents it as a percentage of material specified minimum yield strength (SMYS). This figure is banded in accordance with the safe values specified in ASME B31G which defines maximum limits of hoop stress according to population proximity and density. Using this data it is possible for integrity engineers to make a judgment on the requirement or otherwise of further action. Sufficient data is therefore reported to facilitate an informed judgment on the condition of the inspected unpiggable pipeline without the need to convert it to run in line inspection tools should ECDA be considered too slow, too ineffective and too expensive and a more thorough knowledge of the pipeline condition is required. It is important to note that this data was published in 1992. It is reasonable to assume the savings illustrated are several magnitudes higher in the present time.

Item	Low $/km	High $/km
Caliper Tool	620	810
Launcher/Receiver	500	620
Clear Restrictions	3100	15500
Total	4220	16930

Figure 26 Table depicting the typical cost of conversion of an unpiggable to piggable line based on US data in year 1992 where 42% of natural gas lines and 11% of liquid lines cannot accommodate pigs because of physical limitations such as no pig traps or reduced-bore valve traps and other fittings (Source: US Dept of Transportation, Washington, USA, 1992).

Case Study 1 Assumptions:

1. Caliper tool used to identify restrictions and bends that would need modification.

2. Modification to fit the launcher/receiver combination ranges from $80 - $100k. Assume requirement is every 160km then figures in the table are average cost/km.

3. Restriction clearance assumed as minimum 1 obstruction per km with low in table referencing section replacement to clear tight bends only and high including valve replacement.

4. Figures include cost of loss of throughput.

Case Study 2: The Costs of Low Resolution and High Resolution ILI Methods

This example shows that low resolution tools were reported to be considerably less expensive than high resolution tools but in reality can be considerably more expensive. The experience of a Canadian company of using a low resolution pig to inspect a 288km pipeline should be noted. The tool reported 1809 defects requiring excavation to validate the pig inspection. Rather than make these excavations the company re-inspected using a high resolution pig which showed that only 3 excavations were required ("Assessment of Interactive Corrosion by High Resolution Pigging", Canadian Petroleum Association Conference, Calgary, Canada, May 1990). Low resolution tools can therefore lead to far higher costs due to unnecessary excavations. This is also true for high resolution pigs since inspection companies charge for additional analysis of defects or will recommend "calibration digs" to check the accuracy of their pig.

	Low $/km	High $/km
Cleaning	315	315
Inspection	1250	2200
Operator Errors	65	65
Throughput Loss	1800	3600
Total	3430	6180

Natural Gas Pipelines

	Low $/km	High $/km
Cleaning	5620	5620
Inspection	1250	2200
Operator Errors	65	65
Throughput Loss	0	0
Total	6935	7885

Liquid Pipelines

Figure 27 A summary of ILI costs on natural gas and liquid pipelines using low-resolution MFL tools (Source: US General Accounting Office, Report GAO/RCED-92-237 and "A comparison of MFL Technologies" delivered to the conference on "Pipeline Risk Assessment, Rehabilitation and Repair", Houston, Texas, September 1992).

Case Study 2 Assumptions:

1. Throughput loss based on price of $6/mmBtu. (Historical High = $15.38/mmBtu, and Historical Low = $1.05/mmBtu).

2. Cleaning of natural gas pipelines assumes mechanical (scraper tools) only

3. Cleaning of liquid pipelines assumes a split of 65% mechanical and 35% chemical

5 SCT™ APPROVALS AND REFERENCES

Contracts for work performed using SCT™ to inspect client pipelines usually contain confidentiality clauses and Speir Hunter is not therefore at liberty to disclose any information on pipelines specific to companies which own and operate them. Similarly, personnel employed by those companies and engaged in the evaluation process are not allowed to speak on behalf of or to represent their companies officially. However, the following persons have granted their permission to be approached informally:

NAME	COMPANY	EMAIL	TELEPHONE
Peter Martin	National Grid (UK)	peter.b.martin@nationalgrid.com	+447 1462 444624
Juan Meja	Enbridge Pipelines Inc (Canada)	juan.mejia@enbridge.com	+1 780 420 8589
Greville Turner	Pipe and Tank (South Africa)	greville@pipeandtank.co.za	+27 11 2342 505
Guy Dos-Santos	GRTgaz (France)	guy.dos-santon@grtgaz.com	
Jerome Bonnal	GRTgaz (France)	jerome.bonnal@grtgaz.com	+33 660 559116

Figure 28 National Grid UK's official endorsement of the SCT™ inspection method within their integrity management toolbox.

Below is a release from S Africa (ref Greville Turner):

> *"In answer to your questions:*
> *The pipeline is a steel pipe with a longitudinal weld.*
> *The pipeline is circumferentially welded at 9m intervals.*
> *The coating is a fibreglass reinforced bitumen and, it is believed, the lining is of the same material. The pipeline was constructed in 1956.*
> *We have previously inspected four other locations on this same section based on an ECDA type of study. All of these sites were found to be the locations of circumferential welds that were either uncoated or where the coating had failed. At all locations varying degrees of corrosion were detected. Each of these locations and most coating defects in general, corresponded with SCT™ anomalies. It should be noted that only 49 coating defects were detected on the full 1500m length of pipe. Most of these coating defects were very large (uncoated joints). One of the SCT™ anomalies which we inspected was a site of external corrosion but a coating defect had not been detected at this point. Upon physical inspection a number of very small coating defects were found and corrosion had occurred underneath the coating. There were two very large coating defects either side of this point which may have obscured the detection of these small defects."*

6 TECHNICAL SPECIFICATIONS

Product Information:

The SCT™ Inspection System is a non-contact, non-destructive and passive technology that collects magnetic data occurring naturally in the target pipeline to assess pipeline integrity, produce 3-dimensional mapping of a pipeline's position and identifying features such as casings, and wrinkle bends.

- Capable of detecting Stress Concentration Zones (SCZs) caused by:
    - Metal Loss (internal or external)
    - Cracks and linear defects (including SCC)
    - Dents
    - Sagging or Bending caused by ground movement

- 3 Dimensional Mapping & illustration of a pipeline's position using a combination of magnetic data and survey grade GNSS technology
- Estimates depth of burial with a reading every 2m to 6m
- Detects ferromagnetic casings
- Detects changes in wall thickness and diameter

Scope of Work

- Diameter of surveyed pipelines: >150mm (6 inch)
- Pipe wall thickness: >3.0 mm
- Pipeline Depth: Optimal depth of burial is when the pipeline is within a distance that is twelve times the diameter of the pipe from the UNISCAN scanner bar

Sensing Passive magnetic technology

Accuracy

Pipeline Lateral position:	Within 100 mm.
Pipe Depth:	± 5% of the actual depth to a confidence level of 95%.
GNSS Positioning System:	Positioning Accuracy: Survey grade multi constellation GNSS system. Accurate to 15 mm relative to fixed point without post correction (95% confidence). 15 mm absolute after post correction.
SCZ Location:	Within +/- 1m as predicted by geocoordinates. This refers to the accuracy of the positioning of the geometric centre of the SCZ. Defects, single or multiple, causing the magnetic anomaly will be contained within the anomaly zone but their precise position and quantity is not defined.

Probability of Detection, Missed and False Calls

Probability of Detection:	Not less than 80% of verified inspection locations with a confidence level of 95% in conditions where no magnetic interference is experienced.
Missed Calls:	Not more than 20% of verified inspection locations with a confidence level of 95% in conditions where no magnetic interference is experienced.
False Calls:	Not more than 20% with a confidence level of 95% in conditions where there is no source of magnetic interference.

Data

Memory USB:	Durable industrial grade USB for data collection which will store > 200km of pipeline magnetic /GNSS data
Data Processing:	Offline data analysis using UNISCAN Tools™

Physical and Environmental Qualities

Environmental protection:	IP-66
Batteries type:	Lithium (GNSS): Ni-MH (UNISCAN)
Framework:	Carbon Fibre
Continuous work:	Not less than 12 hours
Operating Temperature:	-25ºC to 45°C
Max Survey Length:	Unlimited
Operating Hoop Stress:	>65Mpa current or historical
Weight:	7Kg (including GNSS Rover and batteries)
Sensory array dimensions:	1100mmm x 140mm x 120mm

Storage and Transport

The UNISCAN System is stored and transported in a protective 'Peli' case with the dimensions of 147 x 47.5 x 26.5 cm and weighs 26.8kg

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