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EVALUATION OF ABOVEGROUND 'INTENSIVE' CIPS / DCVG SURVEY METHODS

Piotr Lewicki
ROSEN UK Ltd.

Daniel Cassarino
ROSEN UK Ltd.

Dave Baglin*
ROSEN UK Ltd.

ABSTRACT

Pipeline operators require accurate inspection data to evaluate the satisfactory effectiveness of the external corrosion control measures in place, i.e. coating condition and cathodic protection levels; in order to adequately manage the current and future risk of external corrosion. Aboveground surveys are used to obtain these critical data sets, with the Direct Current Voltage Gradient (DCVG) and Close Interval Protection Surveys (CIPS) being the most commonly used techniques.

The DCVG survey technique relies on measuring the change in the electrical voltage gradient in the soil along and around the pipeline to identify coating holidays. On the other hand, the CIPS technique involves recording the pipe-to-soil potential at short intervals (every 1 or 2 m) along the complete pipeline route using a trailing cable. The cable is attached back to the nearest test post for electrical connection to the pipeline in order to ultimately assess the effectiveness of the CP system in place.

Whilst CIPS and DCVG have been effective techniques in fulfilling their original respective technical objectives (within the frame of their respective limitations), the pipeline industry has witnessed the development of the 'intensive method', which allows the operator to combine / integrate the pipe-to soil measurement and coating holiday detection into ONE unique survey.

This integration of CIPS and DCVG into one survey has been seen by many pipeline operators as beneficial due to obvious logistic and economic reasons. However, the availability of the "intensive

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method" has generated technical debate between those praising the effectiveness of this technique, and those attached to the traditional separate CIPS and DCVG.

The technical argumentation discussing which approach (i.e. intensive method or CIPS / DCVG separately) is more reliable, or what the respective technological / operational challenges (if any) associated with the intensive methods are, is very sparse in the public domain.

This paper looks into the very detail pertaining to the functionality and effectiveness of the intensive survey methods, with emphasis given to understanding technological and logistical aspects, whilst gaining first-hand information from pipeline operators and managers fully versed in the methodologies in question.

Note: The use of the terminology of 'intensive method' within this report refers to ONE unique survey which simultaneously integrates / combines; CP performance (via CIPS) and coating defect assessments (such as DCVG). Throughout the review purpose numerous references to such surveys including 'combined', 'hybrid' and 'intensive' surveys have been identified. Consideration has been given to technology which provides both CIPS and coating assessment outputs and also multiple technologies which are used to provide the combined output of CIPS and coating assessments.

1. INTRODUCTION

The process for developing this paper, into intensive survey methods, was done so via a comprehensive literature review which considered a number of aspects, including a review of pertinent standards, papers and operator experiences into the survey methods in question.

In order to structure the findings the following aspects have been considered as the pertinent discussion points;

- **Presentation of Techniques** - Presentation of industry recognized separate, Close Interval Protection Surveys (CIPS), Direct Current Voltage Gradient (DCVG) and intensive survey methods, which included a review of industry standards and guidelines relating to use of intensive survey methods versus separate CIPS and DCVG surveys.
- **Reliability Review** - A comparison of reliability between separate CIPS, DCVG and intensive survey methods, inclusive of the following aspects;
  - Identification of potential Technological limitations / challenges using intensive / combined methods.
  - Identification of situations where intensive / combined methods should not be used.
  - Identification of situations where intensive / combined methods are the preferred options.
- **Future Developments**- Academic / industry research into further developments of the intensive methods including integration of additional surveys.
- **EPRG Recommendations** - Provision of recommendations for development of intensive surveys within the EPRG framework

2. PRESENTATION OF TECHNIQUES

Derived from the process, detailed above, industry knowledge and feedback from EPRG members, the following 'overriding' techniques associated with carrying out CIPS and DCVG surveys were identified;

1) **Stand Alone CIPS**
2) **Stand Alone DCVG surveys**
3) **Simultaneous CIPS & DCVG surveys**
4) **Lateral Intensive CIPS / DCVG** –
   a) Lateral CIPS / DCVG 4 person technique
   b) Lateral CIPS / DCVG 5 person technique
5) **Trailing Intensive CIPS / DCVG**
6) **Additional 'Hybrid' Surveys**
   a) Side Drain Cell to Cell Surface Potential Gradient Surveys
   b) Hot Spot Cell to Cell Surface Potential Gradient Surveys

2.1. Stand-Alone CIPS

Stand-alone CIPS are conducted as an above ground, non-intrusive survey, which is used to determine the effectiveness of cathodic protection systems of buried or immersed pipelines.

Process

Whilst there are a number of variant methodologies used in the undertaking of CIPS; from that given in the applicable standards, to pipeline owner and survey operator preferences ; with respect to impressed current cathodic protection systems (ICCP) vs. galvanic systems, the surveys are typically carried out by the following process;

A two or three person team traverse the pipeline route capturing both energized On potential and polarized Off potential measurements (ICCP applicable systems), at close interval distances (typically 1-2 m separation).

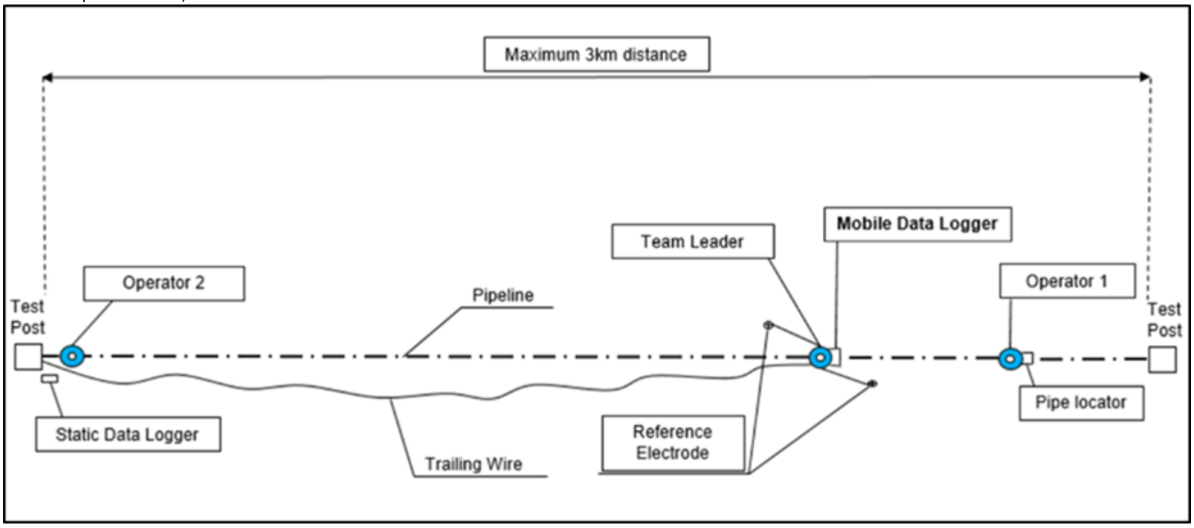

Figure 1 – Schematic representation of the Stand-Alone CIPS survey.

The subsequent data sets captured are then typically presented in tabular and graphical format, aimed at providing the operator with the following information;

- Plotted 'Mobile' On / Off potentials against a chainage / relevant distance
- Plotted 'Static' On / Off potentials against a chainage / relevant distance (often at an offset value to enable analysis process)
- Identification of CIPS defects (CIPS defect categories may differ according to operator or industry standards)
- Applicable minimum / maximum protection criteria
- Additional data / comments pertinent to the survey in question (Power supplies / Test post (TP) / Crossings (road / river / rail etc.) / foreign structures / overhead cables etc.)

The analysis and criteria for the stand-alone CIPS survey techniques are internationally documented in significant detail within all major international corrosion standards relating to the integrity of buried, metallic pipelines / assets.

2.2. Stand-Alone DCVG

DCVG is an above ground, non-intrusive survey technique which is primarily used for locating coating defects on buried pipelines. The principle of DCVG is to record soil to soil potential difference measurements, caused by voltage gradients in the soil due to cathodic protection (CP) current flow at open coating defects.

Process

DCVG surveys are typically carried out by a two person team, with the DCVG operator traversing the pipeline route testing for a pulsing voltage gradient at regular intervals, in a longitudinal direction across the pipeline route. Once an open coating defect is approached, the DCVG voltage increases, this is noted via a swing / deflection in the DCVG voltmeter, the deflection subsequently reverses once the defect is passed enabling the operator to pinpoint the defect epicenter.

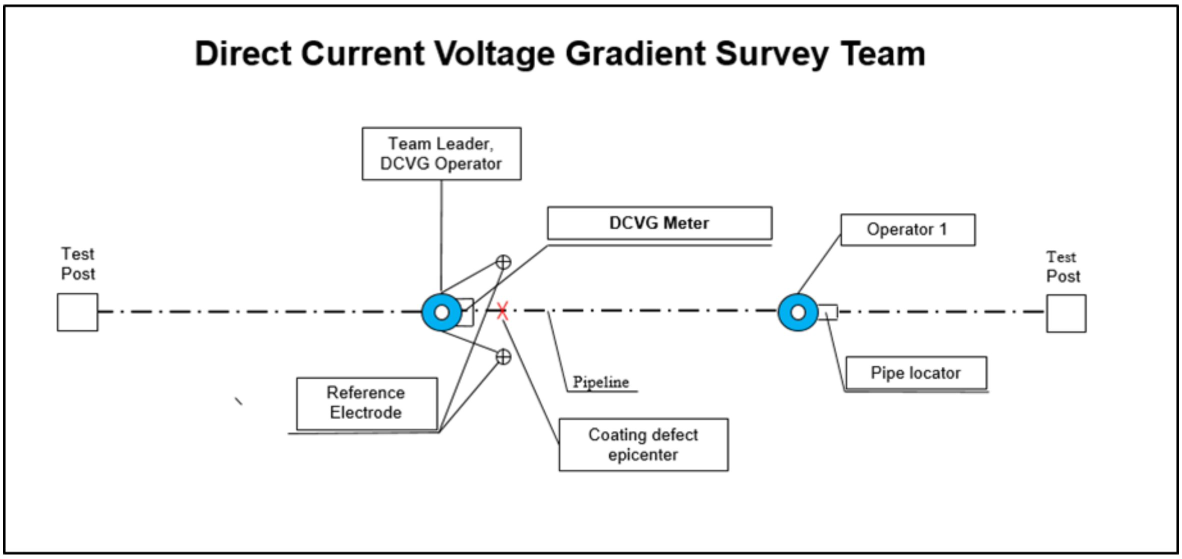

Figure 2 – Schematic representation of the Stand-Alone DCVG survey

Coating defects are then assessed via a calculated method to provide a severity rating / category via an IR% (current (I), resistance (R)). These can then be cross referenced against the operator's applicable standard / adopted criteria.

As with CIPS, the analysis and criteria for Stand-alone DCVG survey techniques, are internationally documented in significant detail within all major international corrosion standards relating to the integrity of buried, metallic pipelines / assets.

2.3. Simultaneous CIPS / DCVG

Whilst CIPS and DCVG are recognized techniques for assessing CP performance and coating condition, the two survey techniques are 'typically' identified as separate surveys. However, attempts have been made to perform these surveys simultaneously in order to;

- Increase efficiencies and save time.
- Reduce costs associated with performing two independent surveys across the same pipeline route.
- Conducting simultaneous surveys at the same time can provide the same operational and environmental conditions, thus enhancing the analysis process.
- Reduce inherent risks associated with conducting numerous pipeline surveys.

Process

In principal, simultaneous CIPS / DCVG surveys are carried out via the use of standard survey equipment as utilized when conducting stand-alone surveys. Selection of a suitable survey switching frequency is an important aspect, for which the industry recognized approach is for a CIPS ratio of approx. 4:1 (On / Off) whereas DCVG is typically inverted. Whilst there are no hard and fast rules relating to the size of a team carrying out simultaneous CIPS / DCVG, due to the nature of the equipment being used it is envisaged that a typical team would need to consist of a minimum of 4 persons.

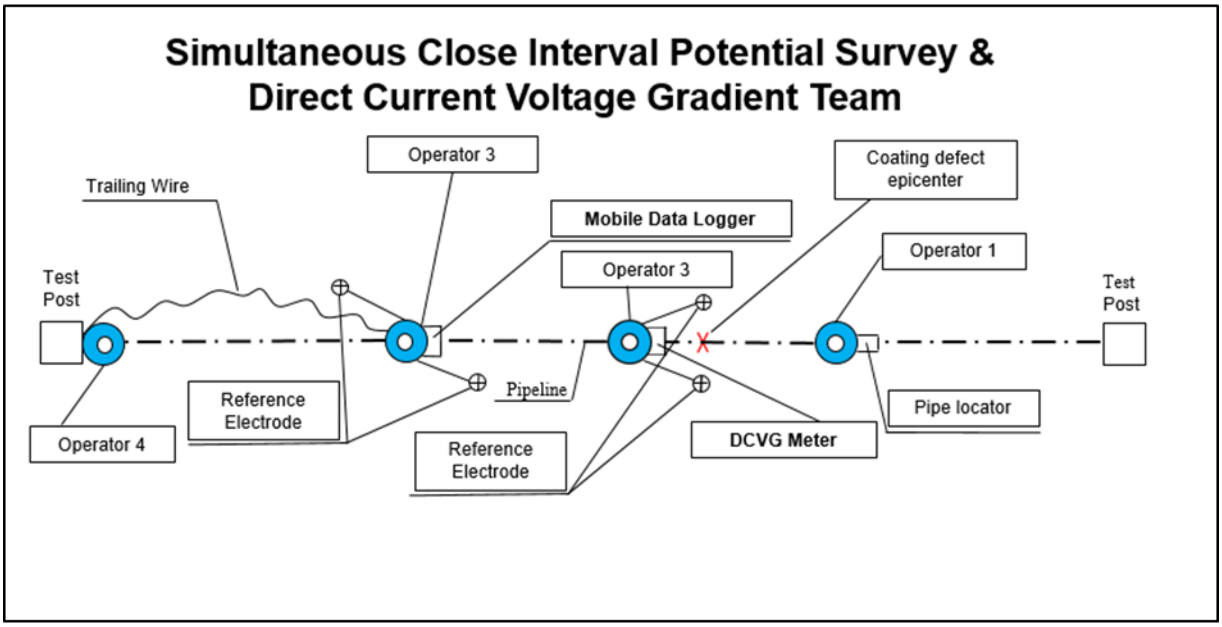

Figure 3 – Schematic representation of the Simultaneous CIP DCVG survey.

Analysis of the subsequent data sets is performed as would be in stand-alone surveys with captured On / Off potentials presented in tabulated and graphical format, overlaid with DCVG defects categorized as an IR%.

There is no specific standard reference or recommended practice to carrying out simultaneous CIPS / DCVG surveys. There are however a number of published papers [9 & 16], which document proven methodologies for performing simultaneous surveys.

2.4. Lateral CIPS 'Intensive' Survey Technique

Lateral CIPS surveys are one of the current 'intensive' methods whereby the overriding principle is to measure CP performance whilst simultaneously identify coating defects in the same passage of survey.

Process

Such survey techniques are carried out by recording the CP potential data (On / Offs) with one reference electrode directly above the route of the pipeline, whilst a second electrode is located in a lateral orientation (perpendicular to the pipeline). The electrodes are separated at a pre-agreed, fixed distance, recording simultaneous potential data on a separate channel within the equipment being used. The difference in the potential data between the two electrodes can then be calculated and used to identify possible coating defects along the route of the survey.
There are two recognized techniques of lateral CIPS, these are the 4 person method (as above) and the five person method, which utilizes an additional reference electrode, placed laterally to the center electrode on the adjacent side of the pipeline route.
Subsequent data sets are presented as such;

- CIPS – data is presented as would be in a stand-alone survey with On / Off potentials.
- DCVG – this differs significantly from a stand-alone DCVG, with various assessments referenced such as 'coating indication severity and weight of a defect. Essentially the overriding difference is that DCVG captures an IR% based upon a calculation which is absolute to the survey process, whereas lateral DCVG is reliant on the voltage difference measured through the soil at two separate points.

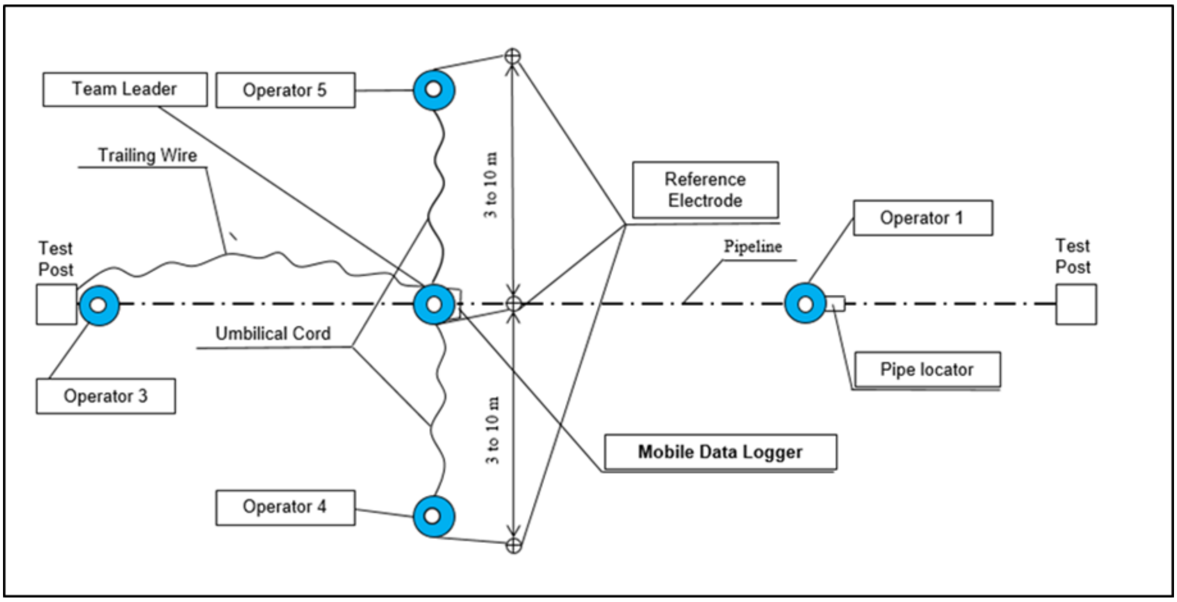

Figure 4 – Schematic representation of the lateral CIPS survey (five person technique)

The review of international standards did identify a number of references to lateral CIPS / DCVG surveys (defined as 'intensive or hybrid' surveys), as acceptable alternatives for CP performance and coating evaluation assessments. It should however be noted that there is significant variations relating to operational aspects within the varying standards, this is evident when considering the separation distances from the centerline reference electrode to that of the lateral reference electrode. In addition, there is little or no guidance or detail pertaining to sizing or benchmarking (for sizing) of coating defects.

2.5. Trailing CIPS 'Intensive' Survey Technique

Trailing CIPS surveys are one of the current 'intensive' methods, as with Lateral CIPS, whereby the overriding principle is to measure CP performance whilst simultaneously identify coating defects in the same passage of survey.

Process

Such survey techniques are carried out by recording the CP potential data (On / Offs) with one reference electrode directly above the route of the pipeline, whilst a second electrode trailed (along the pipeline) at a pre-agreed, fixed distance, recording simultaneous potential data on a separate channel within the data logger being used. The difference in the potential data between the two electrodes can then be calculated and used to identify possible coating defects along the route of the survey.

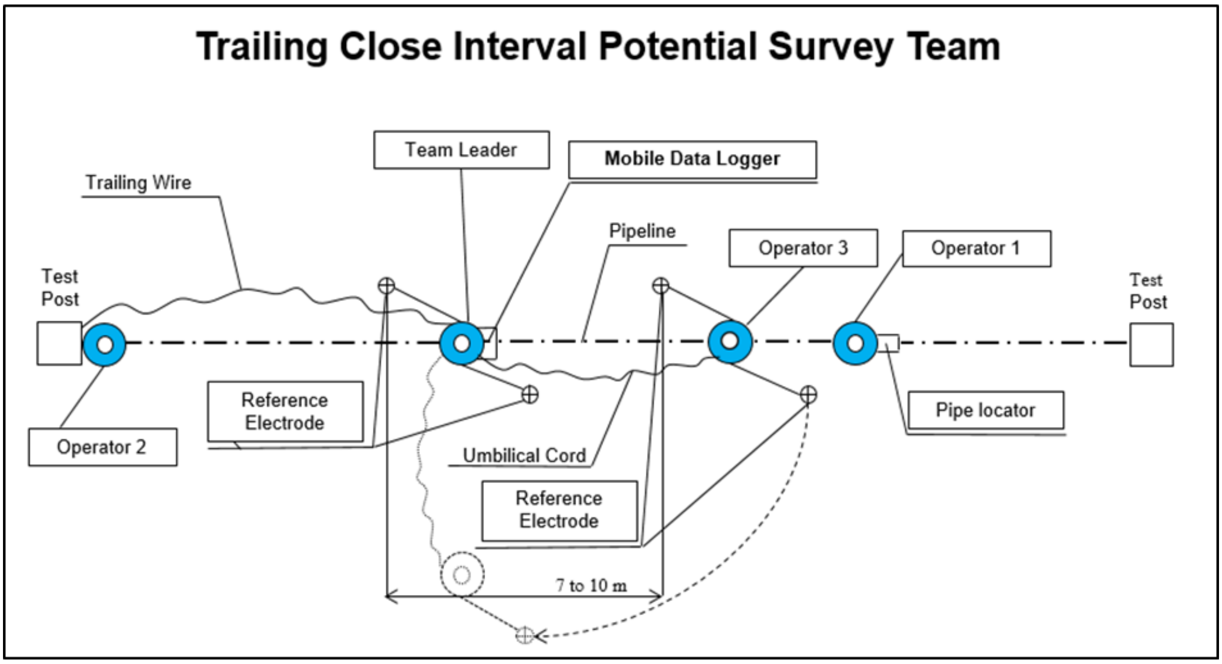

Figure 5 – Schematic representation of the trailing CIPS survey.

The data sets are presented in a similar fashion to those of the lateral CIPS, with On / Off potentials (CIPS) and defect categorizations based upon the voltage difference measured through the soil between the center electrode and the trailing electrode.

During the review process, it was noted that when referenced in standards, there are no common differentiators between lateral and trailing survey technique, often they are defined as 'intensive' or 'hybrid' surveys. With this in mind, all references to separation distances from the center line reference electrode to the trailing reference electrode, when performing 'Trailing CIPS' are as defined in Section 4 pertaining to Lateral surveys. There is however some guidance provided within BSEN 13509 [1] that stipulates the separation distance should be great enough to cover the extent of the voltage gradient.

2.6. Additional Survey Techniques

In addition to the 'intensive' survey techniques detailed within this section, there are a number of additional above ground survey techniques, which are identified, in NACE RP 0502 [5] and NACE SP 0207 [3], as 'hybrid' surveys which can be utilized in similar fashion to DCVG or provide a survey for identifying 'NET protective current'. Whilst these survey techniques, as stand-alone aspects, do not satisfy the terminology associated with this study as 'intensive CIPS / DCVG, as they do not provide a combined overview of CP performance and coating evaluation, the techniques in question have been listed in short detail (below) as potential surveys which could facilitate CIPS or DCVG as one intensive survey technique. The surveys in question are;

- Side Drain DC Cell to Cell Potential Gradient
- Hotspot Cell to Cell Potential Gradient

These survey techniques are carried out in a similar manner to the DCVG aspect within a lateral / trailing intensive survey, and can be used to calculate the net protective current on a cathodically protected pipeline. This is achieved by recording cell to cell potential gradients across two reference cells, one of which is placed directly over the pipeline centerline, with the second at a pre-agreed distance at a lateral orientation in the side drain method, or axially along the centerline during a hotspot cell to cell survey. The measured difference (between potentials) can then be calculated and used to identify a number of aspects, including;

- Locations of current discharge on cathodically protected pipelines
- Anodic locations on unprotected pipelines

As there is no requirement for these survey techniques to have an electrical connection to the pipeline, it is not possible to accurately assess the CP performance via On / Off potentials as with a CIPS survey. Should On / Off potential data be gathered at nearby test post stations, it is theoretically possible to trend the captured data to identify areas where CP levels may be higher or lower than where referenced. It is believed that such survey techniques may well be open to significant error, and should not be perceived as replacing CIPS.

3. RELIABILITY REVIEW

This review process, has enabled a comprehensive understanding regarding the varying formats associated with 'intensive' survey methods. This, along with discussions held with operators, operatives and manufacturers of survey equipment, in addition to the results of an EPRG questionnaire, have been the basis for the reliability review. The purpose was to conduct a comparison of intensive surveys against stand-alone methods and to identify any potential technological or operational challenges, and highlight where intensive methods should not be used or are the preferred option.

In order to undertake the review there is a requirement to identify a process from which to conduct any comparisons, therefore the following aspects have been identified, which are considered pertinent to undertaking such surveys, these are as follows;

- Operational Aspects
  - Interruption of current sources
  - Survey efficiencies
  - Right of way / access requirements`
  - Execution complexity
- Survey Personnel Aspects
  - Personnel Requirements
  - Personnel Competency
- Industry Guidance / Documentation
  - Established Methodology
  - Defined Criteria
- Data Analysis / Management
  - Data accuracy
  - Data alignment
  - Coating defect assessments
  - Data interpretation

3.1. Reliability Matrix

In order to provide a visual overview of the reliabilities, the following 'reliability matrix' has been generated, based upon the knowledge obtained throughout the review process.
For each aspect detailed above, a score has been provided reflecting the performance value of the survey in question.

The scoring process was scaled between 1–5; with 1 being identified the most efficient / robust and 5 the least.

In the case of stand-alone CIPS and DCVG a cumulative scoring has also been provided in order to identify parity with the intensive survey(s) ability to undertake two survey techniques in one.

Reliability Matrix		Stand Alone		Intensive Methods			
		1	2	3	4a	4b	5
		CIPS	DCVG	Simultaneous CIPS&DCVG	Lateral 4 person	Lateral 5 person	Trailing
Operational Aspects	CP Current Interruption	5	1	5	5	5	5
	Survey Efficiency	1	2	4	4	5	3
	Right Of Way Access	1	2	2	3	5	1
	Execution Complexity	2	1	5	4	5	4
Personnel Aspects	Personnel Requirements	3	2	4	4	5	4
	Personnel Competency	2	3	5	3	3	3
Industry Guidance	Established Methodology	1	1	3	5	5	5
	Defined Criteria	1	1	2	5	5	5
Data Analysis / Management	Data Accuracy	2	1	3	3	4	3
	Data Alignment	3	3	3	2	2	2
	Coating Defect Assessments	1	1	1	3	3	4
	Data Interpretation	2	1	3	4	5	4
Comparative Index per Technique:		24	19	40	45	52	43
Stand Alone CIPS&DCVG combined:		43					

Table 1 – Reliability Matrix

The following Table identifies the weighting / scoring of each aspect, which was the basis for the resulting survey technique score.

	Operational Aspects				Personnel		Industry Guidance / Documentation		Data Analysis		
Weighting Scale	CP Current Interruption	Survey Efficiency	Right Of Way Access	Execution Complexity	Personnel Requirements	Personnel Competency	Established Methodology	Defined Criteria	Data Accuracy	Data Alignment	Data Interpretation
1	Just one	>6Km/Day	min. 2m	Easy	1	1	Comprehensively Documented	Comprehensively Documented	Good	<6m	Easy
2					2						
3	Some	4-5 m/Day	min. 4m	Moderate	3	3	Recognised in Standards	Recognised in Standards	Moderate	6m	Moderate
4					4						
5	All	<4Km/Day	min. 10m	Difficult	5	5	Reliant on local interpretations	Reliant on local interpretations	Poor	>6m	Difficult

Table 2 – Weighting for Reliability Matrix

Note – The scoring within the reliability matrix is based upon the knowledge and experiences of the reporting personnel, and the findings of the review process. This scoring is therefore not definitive and is presented as a guide in order to provide emphasis in the reliability review.

3.2. Interruption of Current Sources

When performing an evaluation of CP performance, whether this be via stand-alone CIPS or an intensive survey method, there is a requirement to interrupt all sources of DC current to the pipeline. This includes any bonds to neighboring structures, galvanic anodes and AC mitigation systems. Whilst there are no clear differentiators between the intensive methods and stand-alone CIPS, considerations should be given to the survey timescales and logistics when the interruption sources are via temporary measures.

Consideration should be given to the time spent on the survey in question. The most efficient process when considering this aspect would be to perform the survey which can cover the most ground in the least time, which according to the results of the EPRG questionnaire and also insight into technical knowledge, may well be a stand-alone CIPS or simultaneous CIPS and DCVG. Should stand-alone methods be preferred however, the second pass survey of DCVG would impact the given timescales, however, there is no requirement to interrupt all sources of current during DCVG, should the required magnitude of swing across the section being surveyed be achieved.

3.3. Survey Efficiencies

From the information reviewed it was apparent that stand-alone CIPS and DCVG are the more efficient survey techniques when considering achievable survey distance in any given timeframe. Additional emphasis can be given when considering other influencing factors associated with the intensive methods such as;

- Additional personnel required performing intensive surveys – Intensive methods are considered more labor intensive to perform requiring a minimum of 4 personnel.
- Operation restrictions – Remaining at a consistent separation distance (lateral) across a pipeline right of way (RoW) may be challenging, especially where separation distances are stipulated at distances between 5 – 20m.
- Applying two separate technologies simultaneously (simultaneous CIPS / DCVG) – any issues / obstructions encountered performing one technique may result in delays, will subsequently impact the second survey, considerations to be given to;
    - Additional channels from which to log simultaneous survey data
    - Additional survey equipment required
    - Additional personnel required across the route, thus increasing the management / supervisory responsibilities

Whilst there is no stated guidance relating to achievable survey distances in any given timescale, according to the results of the review, the following distances were considered achievable with respect to typical comparable scenarios;

Survey Type	Achievable Dist. Per / Day (km)
Stand-Alone CIPS	6
Stand-Alone DCVG	5
Simultaneous CIPS / DCVG	3.5
Lateral CIPS / DCVG 4 Person	4.5
Lateral CIPS / DCVG 5 Person	3
Trailing CIPS / DCVG	4.5

Table 3 – Survey Achievable Distances (Estimated)

3.4. Right of Way / Access Requirements

Considerations must be given to the access requirements when undertaking above ground surveys. Way leaves / access routes etc. across pipelines are often restricted to a set distances, with limitations often incurred due to land owner permissions or physical, geographical features located across the route.
When undertaking a stand-alone CIPS survey across a single pipeline, providing the pipeline route is clearly and accurately located / identified, the survey team should be capable of surveying the route without the requirement to deviate significantly from the pipeline centerline. For this NACE RP 0502-2002 [5] suggests a maximum separation distance between 0.75 m to 1.5 m between reference electrodes.

As the intensive trailing method relies on the voltage gradient (DCVG part of the survey) being recorded by an operator in the same orientation of the lead surveyor, the parameters for access are considered similar to that of a stand-alone CIPS.
This differs slightly when conducting DCVG, typical separation distances range between 1 m – 2 m, whilst this is not considered problematic or limiting, there is a requirement to deviate from the centerline when assessing / sizing a coating defect, with the operator required to measure the gradient to a lateral orientation of remote earth.

Should the chosen survey be a Lateral CIPS / DCVG, then there is a requirement for, one survey operator to traverse the entire route in a lateral orientation. With this technique, the following potential limiting aspects have been identified for consideration;

- Required separation distance of survey team;
    - This was not consistently stipulated in the review of applicable standards, with reference to distances ranging from 3 – 20 m.
- Physical logistics and right of way restrictions;
    - It is envisaged that, at distances such as 5 to 20 m parallel to the centerline, this may cause significant issues when surveying pipelines in urban / congested locations potential physical restrictions (parallel infrastructure / roads / rails / pathways), crops / trees, field boundaries and buildings.
- Changes in ground resistivity;
    - When conducting surveys at parallel orientations, there may be significant fluctuations encountered in ground resistivity, where pipelines are routed next to roads, built up areas or locations of 'made' ground, such changes may present error in the measured data.

With the aforementioned aspects in mind, significant knowledge / understanding of the pipeline route in question, must be considered during the planning stage.

3.5. Survey Complexity

In relative terms, in order to successfully conduct above ground surveys and obtain accurate, reliable, repeatable results, there are a number of aspects which much be consistent throughout, these include;

- Competent, knowledgeable survey operators in the technique(s) being conducted
- Accurate identification of the pipeline route
- Accurate, reliable, fully working equipment
- Established process / methodology

When conducting CIPS or DCVG, as a stand-alone or simultaneous survey, the basic applications of the surveys are reliant on the aspects above. Providing the route across the pipeline is relatively clear and free form significant obstacles, the survey execution remains relatively straightforward and repeatable. Additional complexities do arise with the DCVG element, as defects are located and the requirement to access lateral remote earth is encountered. Such complexities add time to the survey in question, which is further exacerbate by restricted access.

When undertaking lateral CIPS / DCVG, there is a significant added element of complexity when compared to CIPS and DCVG, the aspect in question is the reliance on remaining at a consistent pre-determined separation distance between the reference cell operators. This is evermore present should the survey be undertaken via the five person lateral technique, this may present a required separation distance between the two lateral reference electrode operators to be as much as 40 m, which in terms of pipeline rights of way (including multi pipeline corridors) is considered excessive.

As the trailing CIPS / DCVG survey technique requires the reference cell operators to remain at an axial orientation, the logistical complexities, associated with lateral techniques, are not believed to be as limiting. There is however still a requirement to remain at a set distance, therefore both operators must remain vigilant throughout and communications between the two should be constant.
When conducting above ground surveys, the size of the team in terms of personnel, should also be given prior consideration. It is often considered the case that 'more is not essentially better' and that 'the larger the head count the higher the risk', whether this be from an operational hazard perspective or complications / miss communications between larger teams leading to errors / inaccuracies in survey data.

In addition, when conducting lateral / trailing surveys, the survey lead is central to the data capture process, as the equipment being utilized is recording survey data across two separate channels, therefore the emphasis on the vigilance and skillset of this team member is twofold when compared to the stand-alone operators who are responsible for either CIPS or DCVG data only.

3.6. Personnel Requirements

In order to select the appropriate amount of personnel required to effectively undertake the survey(s) in question; the length and intensity of the survey route is one critical factor, as is the physical operational aspects required to complete a survey in terms of personnel roles and responsibilities. From the review process, the table **Fehler! Verweisquelle konnte nicht gefunden werden.** below identifies the 'optimum' amount of personnel required for carrying out each survey technique considered within this report;

Survey Type	Personnel Required
Stand-Alone CIPS	3
Stand-Alone DCVG	2
Simultaneous CIPS / DCVG	4
Lateral CIPS / DCVG 4 Person	4
Lateral CIPS / DCVG 5 Person	5
Trailing CIPS / DCVG	4

Table 4 – Personnel Requirements

The onus on personnel does suggest that the 'intensive' survey methods are more labor intensive than the stand-alone surveys, due to the additional roles / requirements associated with performing multiple survey techniques in one pass. Therefore, at any given time of an intensive survey being carried out, the likelihood is that there will be additional personnel involved when compared to a stand-alone survey. It should be noted that when carrying out stand-alone CIPS and DCVG; the surveys are independent and are performed in separate passes, typically one after the other. Therefore, whilst the size of the teams are smaller in number, the fact may well be that that the overall time to complete the surveys, as stand-alone, may well present longer time in field for the associated personnel.

3.7. Personnel Competency

Assessing competency of personnel undertaking above ground surveys, does present a 'grey area'. Whilst there is no specific, internationally recognized, pass / fail criteria for CIPS / DCVG operators, which deems personnel competent to undertake the surveys. Often this is depicted in relevant procedures / standards that the lead survey engineer / technician should be fully competent in the survey technique (of choice) and have relevant time dependent experience, in some cases, there is additional guidance stipulating certification to recognized schemes (AMPP / ICorr)

There are training courses available for CIPS / DCVG survey operators which provide insight / guidance into undertaking such surveys, however, for the most part, these are developed and implemented by the manufacturers of survey equipment and are therefore specific to the equipment in question. Often therefore, survey personnel are reliant on internal training techniques provided by the survey vendors and gain the relevant experience through time honored practices gained in-field with fellow company peers / seniors. Whilst such practices do provide a route forward for survey personnel, consideration should be given to issues, inaccuracies and errors. associated with performing such surveys, which may well be passed down from survey operator to survey operator, and without any industry recognized training and competence matrix to capture or govern such aspects, the above ground surveys industry is open to miss-interpretation and error. This therefore places significant emphasis on the capability and integrity of the personnel undertaking the surveys.

As CIPS and DCVG have clear differentiators relating to operational aspects of carrying out such surveys, it's often the case that survey personnel are versed in one technique and not the other. This factor is of paramount importance should the survey being undertaken be an intensive method, as there is reliance on the survey lead to have a comprehensive understanding of both survey techniques and should therefore be fully capable of identifying any operational, logistical or data interpretation issues.

On an international basis, AMPP standard SP0207 [3], does stipulate that persons performing CIS (CIPS) surveys, including hybrid (intensive) methods, must be qualified to understand the procedures contained within the standard, or work under the direct supervision of a qualified person, the qualification status is interpreted as being AMPP CP tester / technician or technologist. This is also the case within AMPP standard TM0 109 2009 [7], which identifies procedures for carrying out DCVG (and other coating evaluation methods). Therefore if adopting the AMPP suite of standards for above ground surveys, the onus on competence / qualification lies with the supervisor or survey lead.

3.8. Established Methodology

The review has identified significant differences between stand-alone CIPS / DCVG and intensive methods when considering the documentation of standardized methodologies. Methodologies and processes for carrying out stand-alone CIPS and DCVG surveys are documented in detail within a number of international standards [1, 3 & 5] with detailed references to both operational and data evaluation aspects.

Whilst there is considerable information available relating to the intensive techniques, much is a reliance on published papers and equipment manufacturer's guidance. Whilst the process for carrying out such surveys can be established through such literature, this does leave a considerable question marks relating to the ability of surveyors to undertake repeatable surveys and also the ability of the pipeline operator to undertake a defined quality assurance process into the legitimacy of the survey being carried out.

Where there is reference to intensive methods in recognized international standards, there is a lack of consistency relating to a number of aspects; such as the requirement for a consistent reference electrode placement, with the following guidance provided within the applicable standards;

- ISO 15589-1 - suggests a distance of 5 to 20 m is required in order to verify CP effectiveness of large coating defects.
- German Standard DIN 50925 - suggests this distance as approximately 10 m at right angles to the protected structure.
- AMPP SP0207- 2007 – suggests that; lateral and side drain potentials shall be recorded offset each side of a pipeline (suggesting five man technique), typically at the distance of approximately two and a half times the pipe depth.

- BS EN 13509 – 2003 states the distance between electrodes on top of a pipeline and lateral to pipeline should be selected to cover the total extent of a gradient (to remote earth).

Such discrepancies present challenges in the undertaking of surveys. Due to the significance of the variance in stated distances it is not clear as to which may present the most accurate survey results. In addition, there are no clear differentiators between lateral and trailing CIPS methodologies, as often the two survey types are categorized together as hybrid or intensive methods only.

3.9. Defined Criteria

The following section is aimed at providing an overview into the level of detail / available documentation relating to the performance criteria associated with above ground surveys. It is noted that CIPS and DCVG as stand-alone survey techniques have internationally recognized criteria for performance and defect assessments with very little criteria variance. CIPS criteria is depicted via the level of polarization being achieved with defects identified and classified based on the magnitude of any positive or negative excursions. DCVG criteria is represented as IR% value with categories presented based on the percentage value in question (see below reference to AMPP RP0502 DCVG Criteria).

DCVG Defect Criteria	
Category	IR%
Category 1	1 - 15
Category 2	16 - 35
Category 3	36 - 60
Category 4	61 - 100

Table 5 – DCVG Criteria NACE RP0502

For simultaneous CIPS / DCVG, the applicable criteria would be representative of the adopted standard and in line with criteria for stand-alone CIPS / DCVG methods as detailed above.

For intensive methods, the criteria associated with the CIPS element of both lateral and trailing CIPS / DCVG, is considered the same as that of stand-alone surveys. For DCVG the criteria for defect assessments is not consistently documented within international standards when compared with stand-alone methods. This is largely due to a number of aspects relating to the differing processes for which the data is captured, and the manner in which the actual DCVG element is calculated. Such is the variation between the techniques that adopting one criteria for evaluating coating defects in intensive data sets, is not considered feasible. It is therefore envisaged that the criteria for providing a coating defect evaluation, is dependent on a number of factors including;

- Actual survey parameters (separation distances / trailing or lateral survey)
- Calculation method
- Factoring of additional data capture (soil resistivity etc.)

With this in mind, the criteria almost becomes survey / scenario dependent and cannot be transferred universally across the entire spectrum of intensive methods. Therefore decisions must be agreed in advance of the survey being undertaken as to what is deemed acceptable or not, in addition, a 'robust' benchmarking process must be considered should any sizing activities be undertaken to support the given criteria.

3.10. Data Accuracy

When undertaking any above ground surveys of buried pipelines the accuracy and quality of the captured data is reliant on a number of aspects including;

- Level of experience / competence of the survey operators / personnel.
- Operational conditions pertaining to the survey in question (weather / terrain / foreign or neighboring infrastructure etc.).
- Adherence to a comprehensive methodology / procedure / criteria.
- Condition / calibration status of the equipment being used.
- Consistency in the actual physical survey function.
- Stray or foreign currents and influences.
- Scrutiny / management and interpretation of the captured data sets.

In all cases, the onus for accurate data is largely reliant on the human factor to identify the issues during the survey process or at the data management stage. Therefore; only competent operators acting under comprehensive methodologies / procedures, should be carrying out such surveys, whilst the captured data should be managed and analyzed by appropriate engineering personnel with a thorough understanding of the surveys being carried out.

Within the review process, there have been a number of concerns identified relating to the intensive survey method data accuracy; these include the following;

- Consistent Separation Distances - As the coating assessment element of the survey is reliant on data obtained between the central and lateral reference electrode(s), any discrepancy between the measured distances during the survey, will have the potential to corrupt the analysis process of the given data set, this may result in coating defect estimations being incorrect.
- Voltage Gradient Signal Strength - When undertaking stand-alone DCVG surveys, the survey operator has the ability to increase the CP current outputs, via local TR(s) or temporary groundbeds, in order to achieve an acceptable level of swing (difference between On and Off potential). In turn, this increases the probability of detection and accuracy of pinpointing / sizing coating defects significantly. For intensive survey methods' the option to increase the CP output is not possible, as this would significantly affect the evaluation of the CP performance. The measured gradient between the two reference cells is therefore absolute and dependent upon the level of CP protection and the local environment / ground conditions across the survey section in question. Where CP levels are poor and the difference between the available 'swing' is low, the potential gradients may be of such a low value that accurate assessment / identification of potential coating defects becomes difficult.
- Coating Defect Locations - With the exception of simultaneous CIPS / DCVG, it is evident that intensive methods cannot be relied upon to accurately locate coating defect epicenters, whereas the stand-alone DCVG method, in the hands of a competent / experience operator can be utilized effectively to identify not only the epicenter, but also the orientation upon the pipe and the corrosion status.
- Complex / Interacting Coating Defects - Additional consideration is required when considering complex or interacting defects. When undertaking trailing CIPS / DCVG for example, should a number of coating defects be grouped within the spacing of the electrodes (e.g. two defects within 10m), then the gradients for the individual defects would likely interfere. Should the case be that the defects in question are of differing size, then it is likely that the smaller of the two is hidden within the gradient of the larger defect, the outcome of which may result in one defect being missed all together and the severity calculation of the second being incorrect.
- Establishing Remote Earth - When considering the lateral and trailing intensive methods, the process for evaluating defect severity is established using a formula / formulas (some variation dependent upon survey type / operator etc.) which is dependent upon the measured ΔV / potential shift (between the reference electrodes placed across the pipe and at the relevant lateral or trailing orientation) during the On / Off cycle. This measurement however, is not representative of the technique used in stand-alone DCVG, whereas the defect severity

calculation is dependent on establishing the measured gradient between the pipe and remote earth (P / RE). When undertaking a stand–alone DCVG survey, establishing remote earth is critical to the defect classification, as this provides the absolute measured gradient value associated with the defect(s) in question, and is therefore an integral part of the defect assessment process.

- Measured Gradient - Should the case be that, the spacing of the electrodes does not cover the entire gradient, owing to any changes in the local environment / soil resistivity / Redox etc., this may have significant effect on the measured ΔV / potential shift, which could be detrimental to the resulting defect assessment. Also without understanding other aspects such as soil resistivity, this process may be challenging when making severity comparisons between defects located across the entire pipeline route. The dependence therefore when undertaking intensive methods is based on the IR voltage drop through the soil across a given distance, and therefore no consideration is given to changes in environment or the pipeline coating resistance.
- Stray Current Interference - When conducting above ground surveys in the presence of stray current interferences, the ability to collect accurate data is significantly impacted. Whilst CIPS surveys are a useful tool to identify the presence of static stray current interferences, there are significant limitations in establishing the actual protection levels in locations affected by dynamic stray currents. Stand-alone DCVG is a technique that may be successfully applied in the presence of dynamic and static stray currents. Manufacturers of DCVG equipment indicate that 'whilst stray current may affect identification of size and corrosion behavior of a coating defect the ability to identify and pinpoint remains constant'. Moreover coating defects are a necessary condition for DC interference to occur on a pipeline, therefore pinpointing defects in such circumstances can be advantageous in the process of identifying 'pick up – discharge locations which may prove worth when considering mitigation. It should be noted however that no the DCVG technique can be challenging when undertaking this in the presence of severe / high AC stray current influence. When considering the use of Intensive methods in the presence of stray current, it is documented in BS EN 13509-2003 [1] and ISO 15589- 1 [2], that the usage of intensive methods 'can be applied only if the pipeline is within the linear part of the potential gradient caused by a foreign current source". It expresses itself where the potential gradients are constant with distance. Should therefore the potential gradients be symmetrical to the pipeline, which often happens when equalizing currents are present, then the 4 Person Lateral CIPS DCVG technique can be applied. However in the event of stray currents in close proximity to the other buried structures or where significant changes in the ground resistivity either side of the pipeline being surveyed are identified, the gradients are no longer symmetrical, in such circumstances the 5 Person Lateral CIPS DCVG technique can be utilized. As the intensive methods are dependent upon the measured difference between two electrodes to establish coating indications, it is understood, at this stage that data sets obtained within locations of significant dynamic stray currents however will present significant challenges at the interpretation stage.

3.11. Data Alignment

With all above ground survey techniques, there is significant reliance on the ability to identify a geographical locations across the pipeline route, with emphasis given to any associated defects / features or points of interest. For the most part this is achieved via the use of global positioning systems (GPS) which are often built into to the data loggers / equipment being used. GPS is a high demanded tool for positioning and synchronization of measurements; therefore, assessing the accuracy of a GPS receiver is an essential phase of any field survey. These accuracies may vary from manufacturer to manufacturer, however for the most part, mobile GPS equipment boasts accuracies, typically within 3-5m. Considerations must be given however, that whilst in most western countries (western Europe / north America / Canada etc.), GPS accuracies as stated above are, for the most part, achievable, this is not always the case in other regions and often GPS accuracies, due to the locations in question may be significantly greater.

Understanding the accuracy of any GPS receiver, through horizontal and vertical root mean square (RMS) error, is key to being able to verify the location accuracy for any field survey. If two or more different GPS data sets from separate field surveys are presented and the accuracy is unknown, overlaying those data sets may well result in severe inaccuracies regarding the actual location of the data sets in question. At best, this could result in a number of scenarios, such as;

- Additional time / effort at the data processing stage to align subsequent data sets.
- Render of corrupt or unusable data sets which may lead to gaps in the assessment process.
- Worst case, result in the data being misinterpreted, with reporting errors leading to misdiagnosis for clients, ultimately presenting an integrity threat to the asset in question.

With the aforementioned aspects in mind, one considerable advantage when undertaking intensive surveys, is that the data overlay process should be absolute.

3.12. Coating Defect Assessments

Stand-alone DCVG is a concept which is internationally renowned and has been long considered the survey of choice among pipeline operators for identifying coating defects. It is considered that, in the hands of an experienced, competent operator, the technique can provide accurate results in terms of defect location, sizing and orientation on the pipeline in question. However, there are a number of operational aspects, which must be satisfied in order to provide such results such as;

- IR difference in terms of 'available swing'
- Ability to accurately establish remote earth locations
- Suitable benchmarking process
- Ability to temporarily stop the survey and capture the relevant detail / data at the defect location, this is not a standard function of the intensive methods.

In addition, the actual coating condition may present a significant factor when achieving the above aspects, however this will be realized in both stand-alone and intensive techniques.

The following aspects are imperative when considering the actual performance of each of the coating evaluation technique;

- 'Pinpointing' Coating Defect Epicenters - When undertaking DCVG surveys, the survey operator traverses the pipeline route with the intention of identifying coating defects, this is achieved by witnessing the direction of the voltmeter needle deflection as the operator approaches and then passes a potential defect. Whilst this process is considered highly accurate, in the hands of a competent / experienced DCVG operator, this does require a break in the progression of the survey. Due to process associated with intensive methods however, it is not possible to consistently and accurately establish the epicenter of any given coating defect, as the survey is continuous. Therefore any information regarding potential defects, is established in the final data review / post process. The survey increments across the pipeline route are therefore critical to the process required to identify the defect location, a typical survey should utilize a spacing of 1-2 m across the entire route (when considering most standards and guidance), and therefore some error will be expected when considering pinpointing. Furthermore the epicenters will not always lie at the crown of the pipe, however may be established at varying orientations around the whole pipeline circumference. This may lead to deviation in recorded measurements and may cause error, especially on large diameter pipelines. As defined further above, it should also be noted that when undertaking intensive methods where the pipeline in question has low / poor CP, the survey parameters are fixed and cannot be compensated against via a temporary increase in CP outputs, as can be when undertaking stand –alone methods. Such scenarios therefore may present a situation where defects are significantly underestimated or potentially missed altogether.

- **Defect Orientation -** When considering orientation of defects, it may be of significant benefit for the pipeline operator to understand approximately, where on the pipe circumference the defect lies. DCVG As a stand-alone method, and in capable hands, orientation approximations can be obtained via a simple mapping process of the voltage gradients achieved during the defect assessment process. As with the pinpointing process, this is not considered achievable during intensive methods due to the continuous progression of the survey. In addition, a significant limitation of intensive methods is the ability to understand the scenario in question when faced with multiple defects within close proximity, such as crown cracking on coal tar coatings, ruffing in tape coatings, blistering of FBE etc. Such defects can be identified within the standalone method by virtue of the iso-potential profiles measured laterally and longitudinally across the survey route.
- **Distance to Remote Earth -** In order to size a coating defect, there is a reliance on the survey operator to accurately establish the remote earth location, perpendicular to the coating defect epicenter being assessed. It is important at this stage to understand that, the remote earth distance is influenced by numerous aspects, which are not within the control of the operator in question, such as; changes in ground resistivity, pipeline depth of cover, available IR difference, access across the pipeline right of way etc.. In additional the change in the measured gradients may also be effected significantly and is not therefore absolute. When conducting stand-alone DCVG, the operator has the ability to negate a number of these aspects, simply by confirming the given distance to remote earth by walking to it (where access permits) and measuring the distance and total measured value of the voltage gradients from the defect epicenter to remote earth. When conducting lateral intensive methods however, the reference electrode is placed at a pre-determined, consistent distance for the entirety of the survey, therefore the entire voltage gradient may not be covered, which may lead to error in the defect severity assessment process.
- **Benchmarking -** When undertaking DCVG surveys, it is possible to provide defect sizing estimations, however a robust benchmarking process must be implemented and adhered to. This can be achieved via excavation and physical measurement (of an example defect) or by coupon assessments of a known size. In the case of intensive methods, a robust benchmarking process may also be carried out in order to provide some estimation of a defect size, however it may be required to factor in additional conservatism when making any estimations based on the actual 'known' parameters / restraints surrounding the survey process (spacing of electrodes / ability to pinpoint / soil resistivity etc.).

3.13. Data Interpretation

The data interpretation process associated with above ground surveys of any nature, is dependent upon a number of significant factors, including;

- Accuracy of the data being reviewed.
- Experience / competence / knowledge of the engineer performing the interpretation (relating to the method in question).
- Influencing factors such as, environmental aspects / neighboring (interfering) infrastructure / knowledge of the route etc.
- Ability to overlay data sets.

For the most part, when analyzing CIPS data, the emphasis is given to the captured On / Off potentials and evaluating these against the applicable criteria. The personnel responsible for the analysis / interpretation of the given data can then review the final data sets with emphasis on making relevant decisions based on the applicable criteria. In turn the associated GPS co-ordinates can then be utilized to identify the location of any potential defects, at this point additional information / data can be utilized to add emphasis to the situation in question thus aiding integrity based decisions.

With DCVG surveys, the data capture process is dependent upon the equipment being utilized; for analogue DCVG there is a dependency on handwritten / hand processed data by the survey operator, whereas electronic data capture equipment provides the operator with the option to download the data in a relevant spreadsheet format. The subsequent data sets are then presented in the relevant format and ultimately provided to the client in a tabulated fashion depicting pertinent information such as IR% value and defect categorization vs given criteria. As with CIPS data this can then be evaluated against the relevant criteria or operator standards.

As with the stand-alone methods, for the most part, data obtained from intensive methods is generated in a similar fashion (spread sheet / data files etc.). The actual content of this is dependent upon the survey being performed, however for the most past will include; CP levels across the route of the pipeline (On / Off potentials) and the gradient data from associated lateral / trailing technique. The actual interpretation of the coating defect aspects then becomes dependent upon the survey methodology and the agreed process for which the reported data is to be presented At this stage any additional data that is required may also be factored in (soil resistivity etc.) to assist in the final classifications of any defect being evaluated.

The interpretation of data pertaining to intensive methods is not clearly defined within the standards reviewed within this process, it is however detailed within NACE SP0207 [3] that; whilst it does not address data interpretation of intensive methods, there is reference to the competency of the operators and that data should be interpreted by persons experienced in such methods. As discussed previously within this report, there is an advantage to intensive methods at the interpretation stage, as the overlay of the captured CP and coating data can be more accurate due to both surveys being ran together and an aligned GPS co-ordinates. However the final data assessment pertaining to intensive methods does present a grey area when considering the evaluation process due to lack of defined criteria and having to deal with multiple data sets and calculations. This is considered more so an issue when dealing with dynamic stray current interferences, therefore some conservatism may be required when making any integrity based decisions and considerations should be given to any additional data / information that may be available.

When considering interpretation and evaluation of any CP or coating data sets, the quality of the captured data is always dependent upon the circumstances from which it was obtained, therefore robust operational procedures / methodologies and experienced integrity biased operators are key to the process. In turn only competent personnel with experience in the surveys and data sets in question should carry out the interpretation / evaluation. Wherever possible it is also suggested that no data sets should be reviewed in isolation, and any additional information or associated data should be factored in prior to making any integrity based decisions.

4. SUMMARY

With the advent of the intensive methods, such is the demand now for manufacturers of CIPS / DCVG equipment to facilitate this market. This has also seen the rise of additional surveys with emphasis given to carrying out as many 'pertinent' surveys in the one pass as possible. With the advancement in survey technologies there is a need for greater understanding of their capabilities and limitations with emphasis on providing not only efficiency but accurate, quality survey data which can assist in the integrity decision making process required by pipeline operators.

Prior to conducting any above ground surveys, it is of considerable importance to hold a thorough understanding of the actual pipeline specifics, associated operational and environmental aspects and the route in question, as these will ultimately steer the decision making process associated with selecting the most suitable survey type and accompanying technology. Should the case be that the operator is required, as per the governing standard, to conduct both CIPS and coating evaluation surveys, then an intensive method, at first glance, may be considered the most viable option; however, it is at this intersection that considerations should be given to the logistical challenges that may present themselves throughout the survey route.

The development of a specific survey strategy for the pipeline in question is therefore of significant value during the decision making process. Emphasis should be given to considering what's actually achievable and how we can maximize the amount of pertinent data available. It's often the case, when performing CIPS, that significant portions of the pipeline route (typically >15%) cannot be accessed for many reasons, including; road / rail / river crossings, watercourses, urban / built up locations, areas which are considered CP stranded (no available test posts) This could therefore accumulate to significant gaps in associated data sets when considering scenarios of cross country transmission pipelines which cover can 100s of kilometers in relevant distance. Should the case be that an intensive survey method is the choice, then the requirement for a constant electrical connection to the pipeline (via trailing cable) will subsequently leave the survey open to any issues identified in this review. One option is therefore to utilize numerous technologies as part of a targeted strategy, for example, conducting CIPS across all sections which are accessible to the survey team and targeting locations which are problematic / non accessible to CIPS with supplementary surveys which target the pipeline coatings, such as DCVG / ACVG / PCM / Current attenuation). In addition any significant defects associated with the CP performance can then be subjected to targeted coating surveys.

5. REFERENCES

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