Combined Close Interval Potential Surveys and Direct Current Voltage Surveys for Increased Pipeline Integrity

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Summary

With today's electronic instrumentation, it is possible to combine close interval potential surveys (CIPS) with direct current voltage gradient surveys (DCVG) of buried and underwater pipelines for improved accuracy in assessing the level of cathodic protection combined with locating coating defects without spatial errors. Modern electronic survey instruments are capable of stamping each reading with the time, date and sub-metre GPS coordinates. This provides information for accurate mapping of the pipeline location, current state of the cathodic protection system, and further allows personnel to accurately locate areas requiring excavation for coating repair. This paper will show by example how combined CIPS and DCVG surveys undertaken to NACE standards are of benefit to pipeline operators in ensuring cost- and time-effective integrity management of their pipeline systems.

1 Introduction

Traditionally direct assessment of external corrosion of pipelines has been undertaken as a two step process with a close interval potential survey (CIPS) undertaken to determine the level of cathodic polarization and an analogue (See Figure 1) direct current voltage gradient (DCVG) survey to determine the location of coating defects or holidays. Undertaking the CIPS and DCVG surveys separately leads to spatial errors.

Figure 1 Analogue DCVG Meter

Further, if the surveys are not done concurrently, errors can result due to differences in soil moisture content, the skill of the operators undertaking the survey, changes in the level of cathodic protection and the inability to accurately mark or record the location of coating defects, they must be manual staked out. (See Figure 2).

Figure 2 DCVG Surveyor

2 Direct Current Voltage Gradient Surveys

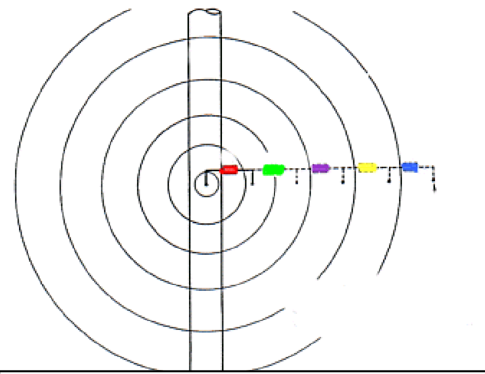

Figure 4 Voltage Gradients at Defect

A DCVG survey locates coating defects; it does not indicate the level of cathodic polarization on a pipeline. A DCVG survey consists of applying pulsed DC current to a pipeline by synchronously interrupting the rectifiers (See Figure 3) and then measuring the voltage shift in the soil along a pipeline (See Figure 4). When a defect is present, a voltage gradient will be present in the soil. This can be measured as a voltage between two electrodes in contact with the soil (As shown in Figure 5). When undertaking a DCVG survey with a single surveyor, it is essential to take the readings moving out from the center of the defect, summing the values in order to arrive at the total voltage gradient associated with the defect. The voltage gradient measured follows Ohms Law in that the Voltage Gradient is equal to the current flow multiplied by the resistance of the electrolyte path (VG = I * R) thus the Voltage Gradient measured is influenced by the resistance of the electrolyte path, the spacing between the electrodes and the current being delivered to the coating defect. The effective distance that a defect can be measured at can be expressed mathematically as shown in Earth Resistances by G.F. Tagg. In order to make the calculation, the coating defect or holiday must be resolved as a hemispherical electrode.

Figure 3 Current Interrupter

Figure 5 DCVG Surveyor

2.1 Equivalent Hemisphere Associated With A Defect

The equivalent hemisphere associated with a defect as expressed in Earth Resistances written by G.F. Tagg published by George Newnes Ltd. London England in 1964 is presented here.

The total resistance of a hemispherical electrode is $R_{\infty} = \frac{\rho}{2\pi r}$ where *r* is the radius of the sphere. This assumes that the defect in question is of similar surface to a sphere where the length of the defect is equivalent to 2*r*.

The resistance at distance r_1 is found with $R_1 = \frac{\rho}{2\pi}\left(\frac{1}{r} - \frac{1}{r_1}\right)$ This gives a fraction of the total resistance of $\frac{\frac{1}{r}-\frac{1}{r_1}}{\frac{1}{r}} = 1 - \frac{r}{r_1}$ Solving to *x* percent then $r_1 = \frac{100r}{100-x}$

The calculations provide the following results.

Table 1 Distance to Remote Earth for Various Sized Defects

	Distance to read the % of total resistance		
Defect radius	95%	99%	99.5%
5mm	0.1m	0.5m	1m
50mm	1m	5m	10m
100mm	2m	10m	20m

On the surface, the probes are positioned so that one electrode is on top of the pipe and the second is a distance away. Assuming that the depth is *d* and the probe spacing is *l* then the distance to read the total resistance is d_r. $d_r^2 = d^2 + l^2$

Table 2 Probe Spacing to Read Total Voltage Gradient for Various Defect Sizes

	Probe spacing for DCVG at a depth of 1.5m		
Defect radius	95%	99%	99.5%
5mm	Won't read	Won't read	Won't read
50mm	Won't read	4.8m	9.9m
100mm	1.3m	9.9m	19.9m

Note: that the deeper the pipe, the less likely DCVG will pick up small defects.

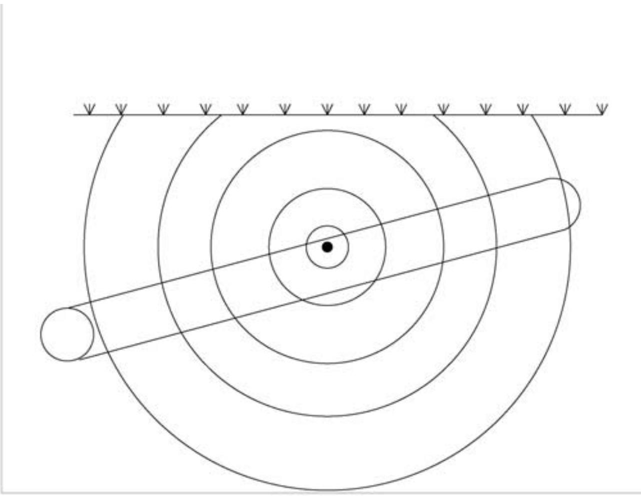

Figure 6 Equipotential lines at a defect

It is apparent from the above calculations that a small holiday at a depth of 1.5 meters has an equivalent hemisphere that does not intersect the surface of the ground above the pipeline and will not be detected by DCVG techniques. Figure 6 shows the Equipotential lines about a defect.

Since DCVG does not measure the rectifier ON or OFF pipe-to-soil potential, practitioners have had to arrive at some method to determine the necessity of repairing the coating defect or holiday. The result is a formula described as % IR.

2.2 DCVG % IR Calculation

The NACE test method TM0109-2009 offers a formula to determine the severity of a coating defect or holiday.

Indication pipe to remote earth DCVG signal magnitudes (P/RE) are calculated using the following formula.

$$\text{Coating Fault P/RE} = S_1 + \frac{d_x (S_1 - S_2)}{(d_2 - d_1)}$$

Where:
P/RE = Pipe to remote earth DCVG signal magnitude (mV)
S1 = DCVG signal amplitude to remote earth at Test Station 1 (mV)
S2 = DCVG signal amplitude to remote earth at Test Station 2 (mV)
d1 = Distance measurement of Test Station 1 (This is zero at the beginning of a survey.) (m)
d2 = Distance measurement of Test Station 2 (m)
dx = Distance measurement of indication from Test Station 1 (m)

Note: The distance between any two test posts should be kept as small as possible. It is not acceptable to simply use the difference between on and off pipe-to-soil potentials at test points (S1 and S2) as the DCVG signal magnitude. All DCVG magnitude measurements must include the voltage gradient from the test station to ground as well as the sum of the voltage gradients to remote earth

2.3 % IR Calculation (Simplified Calculation)

Once an indication is located, its % IR is estimated by measuring the potential difference from the indication epicenter to remote earth (OL/RE). This potential difference is then expressed as a percentage of the total calculated potential shift on the pipeline at the indication location (P/RE), as shown in the Equation below.

Calculated Pipe to Remote Earth at Indication mV

$$\text{\%IR(Coating Indication Severity)} = \frac{\text{Over the Line to Remote Earth mV} * 100}{\text{Calculated Pipe to Remote Earth at Indication mV}}$$

or

$$\text{\% IR} = \frac{\text{OL/RE} * 100}{\text{P/RE}} \quad \text{For Example} \quad \frac{55 * 100}{587.4} = 9.4$$

The indication severity is therefore 9.4%.

Each pipeline is different; the %IR at which a dig is warranted will vary with the soil resistivity and type of coating, the location, the cost and other factors. Without companion rectifier ON and Instant OFF pipe-to-soil potentials, it is difficult for the corrosion engineer to justify digs based only on the % IR without knowing the effect of the coating defect on the polarized potential of the pipeline.

3 Close Interval Potential Surveys

Close interval potential surveys (CIPS) are the mainstay of cathodic protection and are usually undertaken by a surveyor walking over the pipeline measuring the rectifier ON and Instant OFF (polarized) pipe-to-soil potentials at regular intervals along the pipeline (See Figure 7). Since the indicator of the polarized potential is the instant OFF

Figure 7 CIPS Surveyor

pipe-to-soil potential, it is important that the rectifiers be interrupted synchronously preferably using the GPS system for synchronization (See Figure 3). A properly conducted CIPS survey will indicate those areas of the pipeline that meet the criterion for cathodic protection (See NACE SP0169-2007 Standard).

4 Combined CIPS and DCVG Surveys

There are several advantages to undertaking a combined CIPS and DCVG survey. Both surveys are undertaken at the same time by the same surveyors, under the same climatic and soil conditions without spatial errors. This results in more accurate survey data. Further, with modern digital survey equipment, each reading is stored along with the time, date and GPS coordinates; thus defects can easily be located if excavation is required. A further advantage can be obtained by utilizing two surveyors walking over the pipeline approximately seven metres apart (See Figure 8). The seven-metre spacing should capture >95% of the voltage gradient associated with a coating defect or holiday larger than 50mm radius (See Table 2). This spacing has been proven in the field; typically >95% of the voltage gradient is captured within a 5 metre radius from the defect unless the defect is exceptionally large which would result in depressed polarized potentials.

Figure 8 Two Surveyors

When two surveyors are utilized walking over top of the pipeline (as shown in Figure 8), the resultant measurement of a coating defect recorded over top of the pipeline appears as a sinusoidal waveform making for easy recognition of the defect (See Figure 9). This survey technique is explained in NACE Standard Specification
SP0207-2007.

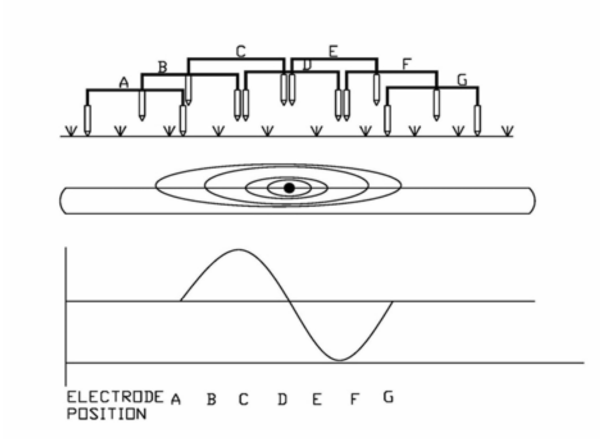

Figure 9 Sinusoidal Waveform at defect

If the second surveyor walks to the side of the pipeline (As shown in Figure 10), then there is a sharp increase in the voltage gradient when the surveyors reach the epicenter of the defect (as shown in Figure 11). If the coating defect is large enough to affect the pipe-to-soil potentials, then a reduction in the rectifier ON and Instant OFF potentials will be apparent.

By utilizing a two-person survey crew walking over the pipeline, the pipe-to-soil potential can be measured simultaneously with the DCVG gradient; thus there is no spatial error. Further, when the surveyors walk over the pipeline a sinusoidal signal occurs at coating defects (See Figure 9).

In Figure 11 the coating defect can be seen as a voltage spike with corresponding reduction in the rectifier ON and instant OFF pipe-to-soil potentials. A corrosion engineer must be cognizant of the level of polarization of pipelines under his jurisdiction. Only a rectifier-interrupted CIPS survey will reveal the level of cathodic polarization on a pipeline.

A DCVG survey will locate coating holidays or defects, but it can not indicate the level of cathodic polarization. A number of practitioners of DCVG surveys have tried to develop a formula that would indicate the magnitude of a coating defect.

Figure 10 DCVG Measurement to Side of the Pipe

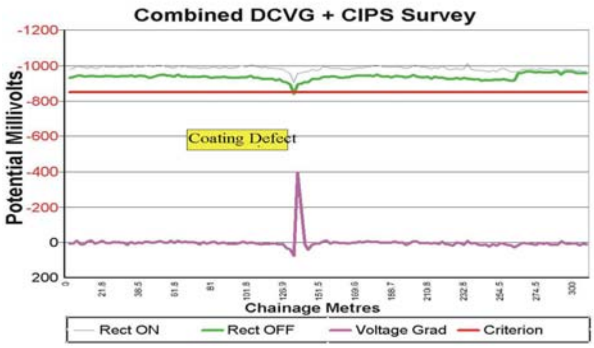

Figure 11 Graph of Voltage Gradient at a Defect

4.1 % IR for Combined CIPS and DCVG

One proposed formula for calculating the % IR for combined CIPS and DCVG surveys developed by R. A. Gummow and S. Segall and R. Reid is as follows.

For a combined CIPS – DCVG survey the %IR can be calculated as follows:

$$\%IR = \frac{K(d,s) * \Delta G_{ol\text{-}d}}{\Delta V_{ol} + \Delta G_{ol\text{-}d}}$$

Where:

$\Delta G_{ol\text{-}d}$ lateral gradient shift as measured between a reference electrode installed over the line (RE1) and a reference electrode (RE2) installed at a distance (s) perpendicular to the line.

ΔV_{ol} potential shift between the pipe and a reference electrode (RE1) installed over the line.

K(d, s) function depending on the pipe depth (d) and the distance (s) between the two reference electrodes used to measure the gradient. For a pipeline 1.2 metres deep where d = 3 metres K = 1.59, for 5 metres K = 1, for 10 metres K = 0.5

5 Examples of defects located by combined CIPS and DCVG surveys

Figure 12 Coating Defect at Joint

The first example is of a defect on a 20-inch gas line where the coating at a joint had deteriorated (See Figure 12) resulting in a small defect that affected the pipe-to-soil potentials (As shown in Figure 13).

This defect was at the 3 o'clock position on the pipeline where petrolatum tape was used instead of the specified shrink sleeve. By combining the CIPS and DCVG survey, the corrosion engineer can easily prioritize the repair of coating defects.

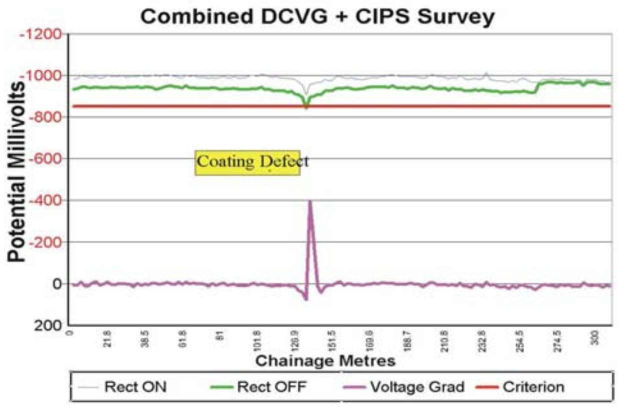

Figure 13 Voltage Gradient Spike at a defect

The second example is of a weld area at a joint where coating repair had not been performed. The defect was on a 20-inch gas line coated with a three-layer polyethylene coating system. The defect was located using a combined CIPS and DCVG survey with two surveyors walking over top of the pipeline. Figure 14 shows the graphical display of the pipe-to-soil potential and the DCVG voltage gradient at the coating miss-out.

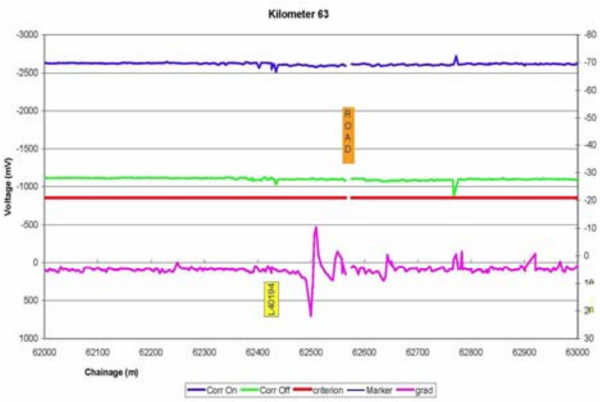

Figure 14 Sinusoidal Waveform at Defect

ct taken after excavation but before cleaning of the pipeline. Although the defect was relatively large, it was not affecting the polarization of the pipeline. With the three-layer poly coating system, very little current was required for cathodic protection of the pipeline.

The third example is of a three-layer polyethylene coated pipeline where third party damage had occurred in the form of a scrape of the pipeline coating by mechanical digging equipment. The graph of the combined CIPS and DCVG survey (See Figure 16) shows multiple sinusoidal

Figure 15 Coating Miss-out at Joint

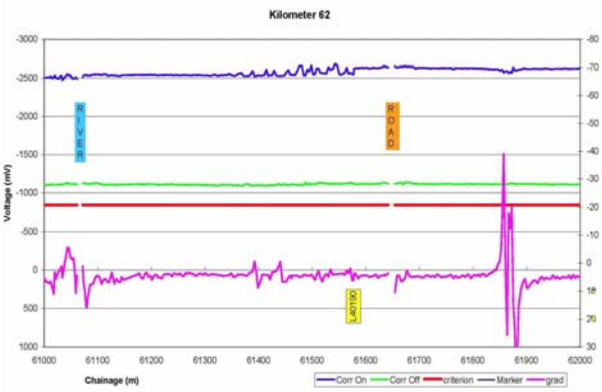

Figure 16 Multiple Sinusoidal Waveforms

Figure 17 Multiple Coating Defects

waveforms at the coating defect. A photograph of the pipeline after excavation is shown in Figure 17.

Although the coating damage shown in Figures 15 and 17 did not affect the polarized potential of the pipeline, it was well protected from corrosion by cathodic polarization and could have been safely left unrepaired. Both of these defects were excavated as a training exercise for corrosion engineers implementing External Corrosion Direct Assessment methodology (ECDA) as described in NACE SP0502-2007.

The sinusoidal waveform produced at a coating defect when two surveyors walk over top of the pipeline performing a CIPS and DCVG survey makes it very easy to visually recognize a coating defect even when the recorded voltage gradient is subject to electrical noise.

6 Conclusion

In conclusion, a combined CIPS and DCVG survey provides the corrosion engineer with accurate information on the level of polarization of the pipeline and the effect of coating defects or holidays. By undertaking a CIPS and a DCVG survey at the same time, spatial errors do not occur and errors due to soil moisture and cathodic polarization as well as operator skill do not influence the survey result. A combined CIPS and DCVG survey can locate small coating defects and third party damage with each reading taken stamped with the GPS coordinates and the date and time the readings where taken.

A DCVG survey does not provide any information on the level of cathodic protection, only information on the integrity of the coating. Repairing coating defects is a double edged sword. As the number of defects is reduced, the surface area of steel from which AC current can discharge is also reduced; thus the current density discharging from the pipeline at any given location is increased and could result in corrosion from DC stray current or AC current discharge.

The corrosion engineer must have sufficient information on the level of cathodic polarization on the pipelines under his jurisdiction that he can assure management that the cathodic protection systems are functioning and providing cathodic protection current to all areas of the pipeline. To reach this level of confidence, the corrosion engineer needs regular current-interrupted close interval potential surveys as they are the only method that indicates the level of cathodic polarization on the pipelines. DCVG surveys can not provide this information.

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