TECHNICAL ASPECTS OF CLOSE INTERVAL POTENTIAL SURVEYS
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Introduction

Cathodic Protection systems are an electrical means of mitigating external corrosion on buried and submerged metallic structures. (primarily steel)

The verification of the Cathodic Protection system effectiveness is assessed by comparison of pipe to soil potentials to meet the requirements of NACE SP0169-2007, Control of External Corrosion on Underground or Submerged Metallic Structures.

Regular testing of the effectiveness of pipeline Cathodic Protection systems is an important means of maintaining pipeline integrity and preventing future problems.

One of the most common methods of testing these systems is the annual test station survey. This requires the measurement and recording of pipe to soil potentials at designated test stations each year. While this is very useful information, particularly for well coated pipelines, the test station data may only represents the potentials on less than 1% of the pipeline surfaces. The test station data does not provide any information on the pipe to soil potentials at a distance from the test station.

Consequently, it has become a standard practice to undertake “close interval potential surveys” (C.I.S.) on pipelines, every few years, in order to provide the data for assessing the effectiveness of the cathodic protection system over the full length of the pipeline. The C.I.S. measures and records the pipe to soil potential on a regular spacing of usually between 3 to 6 feet.

The C.I.S. is an integral part of maintaining safe pipeline operation and will provide in-depth knowledge and information required to maintain pipeline integrity.

Because of the large volumes of data that can be collected during a C.I.S., and to increase accuracy of special measurements, computerized dataloggers are used for the collection of pipe to soil potential data and other field notes. This provides an efficient and viable means of automatic collection of site data.

Copper/Copper Sulfate Reference Electrode

The standard reference electrode used for land based (non saline environment) pipe to soil potentials and C.I.S. is the Copper/Copper Sulfate electrode. This is shown in *Fig 1*. This reference electrode is practical and can be used in a variety of field applications and soil conditions due to its relative stability.

As pipe to soil and structure to soil potentials are measured using this electrode, it is very important that the measurements are accurate. To achieve accurate readings, it is important that the potential of the reference electrode exhibit a stable half cell potential within reasonable limits. While the field stability of the Copper/Copper Sulfate electrode is generally acceptable, it can be affected by contamination and to some extent by temperature and ultra violet light.

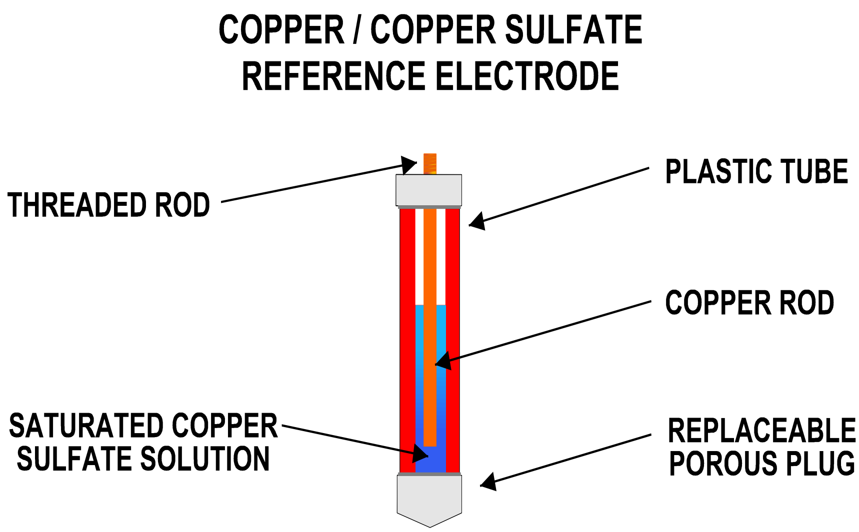


Fig 1

As pipe to soil and structure to soil potentials are measured using this electrode, it is very important that the measurements are accurate.

One predominant type of contamination would be caused by “chloride ions” entering through the porous plug. It is very important that the Copper/Copper Sulfate reference electrode is not used in areas of salt contamination, such as salt water marshes, brackish or saline water. Contamination will result in inaccurate pipe to soil or structure to soil potentials, as the reference electrode will no longer exhibit its normal potential.

Temperature changes can affect the reference electrode potential by up to 0.5mV per degree F. Therefore some daily changes will occur. However, as long as the electrode is not exposed to very large variations in temperature, no remedial action is generally required.

It has been documented that Ultra Violet light can also affect stability and it is recommended that the transparent sides of the electrode be covered with electrical tape to reduce any such effects.

Prior to the taking a pipe to soil potential, it is important to check or calibrate the reference electrode(s) being used. The test is to place the porous plugs of a standard (unused) electrode and the electrodes for the C.I.S. end to end and measure the millivolt difference. Generally, if the difference to the standard is less than 5 millivolts, no maintenance of the electrodes will be required.

Any reference electrodes that fail the test should be kept separate and cleaned as soon as possible to ensure that the survey crew has usable spares.

The simple way of testing electrodes is shown in the schematic *Fig 2*, below.

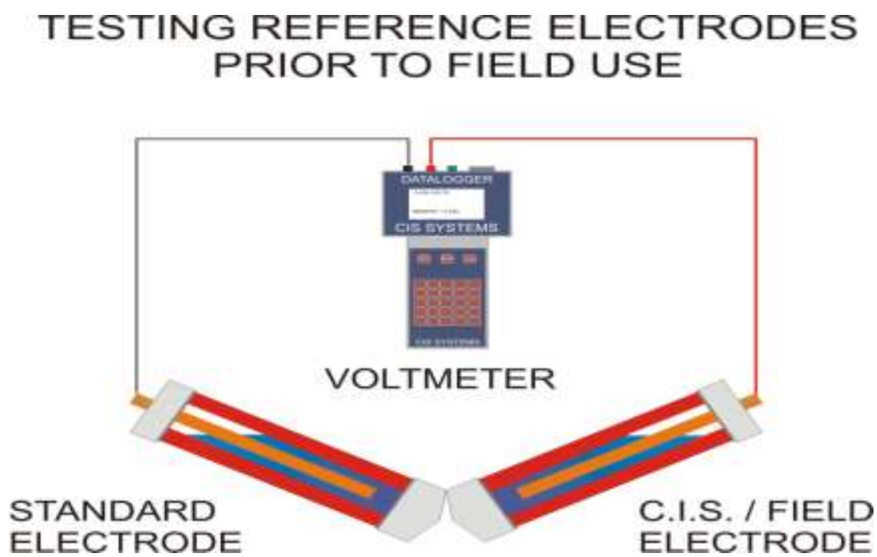


Fig 2

The copper sulfate solution should be saturated, with loose crystals visible, and the end cap placed over the plug when not in use, to prevent leakage and contamination.

Note: copper sulfate gel is available for use in reference electrodes and reduces the leakage problem that sometimes occurs when using the solution. However, it has been found that while the gel is satisfactory for occasional use of the reference electrode, it may not provide sufficient wetting of the porous plug surface for use in C.I.S. applications. Therefore, it is suggested that the gel not be used in C.I.S. applications.

To reduce ground contact resistance, it is also recommended that the porous plugs be cone shaped to permit penetration of the ground surface.

Note that the words “reference electrode”, “reference” and “half-cell” are all terms used to describe the standard reference electrode.

Structure to Soil Potentials

The NACE SP0169-2007 provides the protection criteria to which the measured pipe to soil potential measurements should be compared in order to evaluate the effectiveness of the existing cathodic protection system operation.

Fig 3 shows the typical arrangement at a test station when a pipe to soil potential is being measured.

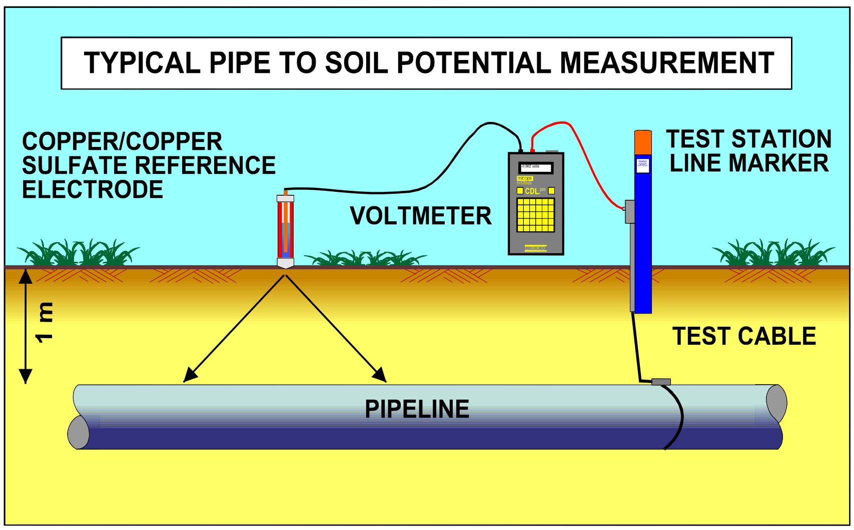


Fig 3

It is important to understand what the pipe to soil potential actually represents.

The reference electrode is placed on the ground surface, over the pipeline, so that the porous plug is in good contact with the ground. The reference electrode is connected by a test lead to the negative terminal of a voltmeter. (the voltmeter must be of high input impedance to ensure accuracy) and the positive terminal of the voltmeter is connected to the pipeline through the test station cable.

The magnitude of this potential will depend on the many variables of the individual cathodic protection system.

This potential represents the <u>average</u> potential of the pipeline at this location. Note that the potential of each square inch of the pipeline in this general location, depending on distance and orientation, may contribute differently to the average potential. There will generally be a larger contribution to the average potential from the top of the pipe and below the reference electrode, than from the pipe bottom and away from the reference electrode. The presence of significant coating defects, even many feet away, may impact the pipe to soil potential.

This means that a potential of –850 mV is only an average, and potentials both higher and lower than this value may contribute to the measured potential.

Close Interval Potential Survey

Fig 4 shows the pipe to soil potentials that may be measured as the reference electrodes are moved down the pipeline. These potentials are the basis of the C.I.S. and provide a continuous pipe to soil profile of the pipeline.

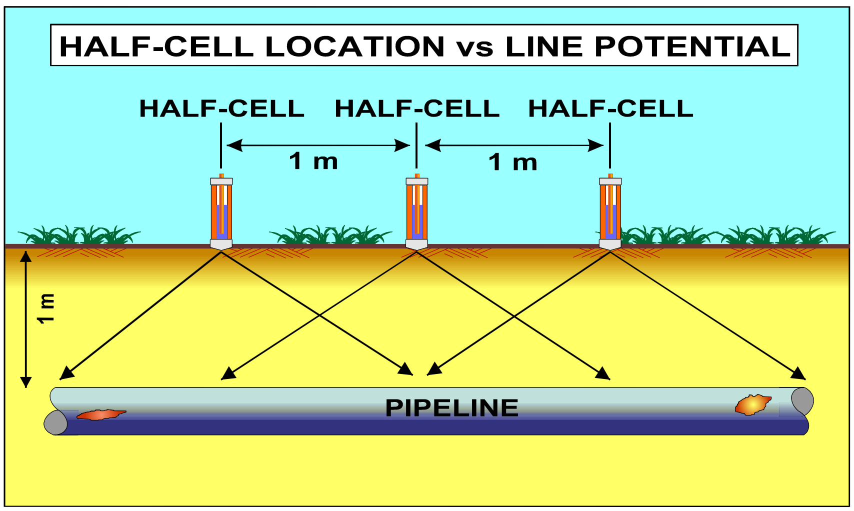


Fig 4

A connection is made to the pipe test lead in a test station, and the pipe to soil potential is measured at numerous sequential locations along the pipeline. The reference electrode spacing is usually between 3 to 6 feet (1m to 2m), and by taking pipe to soil potential measurements over a fixed distance, a graph plot of potential vs distance can be produced.

"On" and "Off" Pipe To Soil Potentials

Pipe to soil potentials recorded with the cathodic protection system operating are called "on" pipe to soil potentials. These "on" pipe to soil potentials include the effects of d.c. voltage gradients (or IR drops) caused by the flow of cathodic protection current in the ground, across the pipe coating and along the pipeline.

For effective comparison to the NACE SP-0169-2007, these voltage gradients have to be temporarily removed while the pipe to soil potential is recorded. This type of potential is called an "off" or "polarized" pipe to soil potential and does not include the inaccuracies caused by the voltage gradient (IR) effects in the “on” potential.

The voltage gradients incorporated in the “on” pipe to soil potential readings are shown in *Fig 5* and can be caused by cathodic protection systems on the line

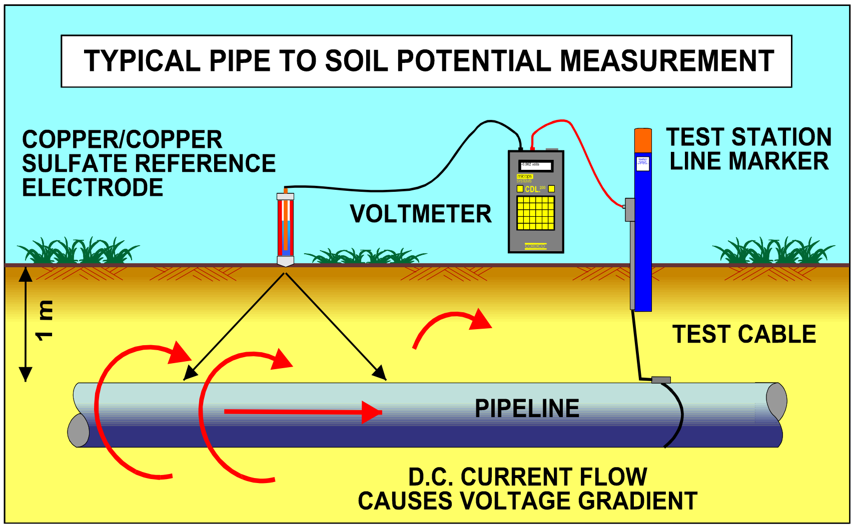


Fig 5

being surveyed, cathodic protection systems on foreign pipelines or from other sources. (e.g. stray d.c. transit systems, magneto-telluric activity) Note that in the case where sacrificial anodes are directly connected to the pipeline underground, the close interval survey can only measure “on” potentials as any voltage gradients caused by current flow from the sacrificial elements cannot be removed. The assessment of the protection levels on this type of cathodic protection system is somewhat more difficult.

Cathodic Protection Current Interruption

Temporary interruption of the Cathodic Protection system current output(s) will remove the direct current flowing in the system and allow for the recording of the “off” pipe to soil potentials.

Some surveys require both “on” and “off’ potentials to be recorded at each progressive location. Other types of survey, e.g. sacrificial anode systems, generally require only “on” potentials to be recorded unless the sacrificial anodes are connected to the pipeline at test stations and can be interrupted.

Impressed Current Cathodic Protection System Interruption

Impressed current systems are a very common means of providing cathodic protection to the external surfaces of pipelines. These impressed current systems utilize power sources (predominantly rectifiers) to provide the d.c. current for protection. This current is forced through ground electrodes, through the earth (or water) to the pipeline as shown in *Fig 6*.

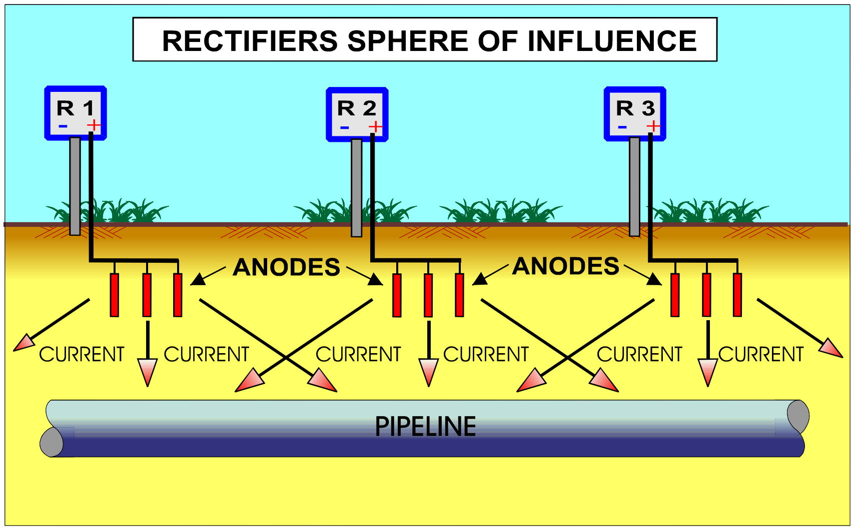


Fig 6

Prior to the start of the survey, the sphere of influence of the power sources or rectifiers needs to be determined to evaluate which areas of a pipeline are affected by each rectifier.

Depending on such factors as rectifier output, pipeline diameter, pipeline coating, ground geological variations and anode type (conventional vs. old pipe as anodes), the effects of the output from a rectifier may be seen up to 25 miles away. (or more)

If true “off” potentials are to be recorded, it is imperative to interrupt <u>all</u> the line rectifiers that affect the line section being surveyed. If some rectifiers are not interrupted, then the recorded “off” potentials will not be true readings.

When interrupting cathodic protection rectifiers, all interruption must occur at the same time in order that true “off” potentials are measured. Therefore, the current interrupters that are installed for a C.I.S. must stay synchronized and all must switch the current “on” and “off” at the same time. The most common type of interrupter used for this type of work uses GPS timing.

Synchronized interrupters can switch the rectifier current at various time cycles, and various ratios of “on” time to “off” time. The selection of both the cycle time and ratio of “on” to “off” time is very important to the viability of the survey and to the validity of the data.

Fig 7 shows a G.P.S. Interrupter being installed at a typical rectifier. The satellite antenna is placed on top of the rectifier so as to have a clear sight of the sky and the satellites so as to receive time signals.

Fig 7

For many surveys, on bare or coated pipelines, a cycle time of 2 seconds ("on" time 1500mS, "off" time 500mS) is used and provides for an efficient and valid survey. In some cases where large "switching spikes" (see later) are experienced, the 2 second time cycle may need to be extended.

The 2 second time cycle and 3:1 "on" to "off" ratio has been found to cause minimal depolarization, even on bare pipelines.

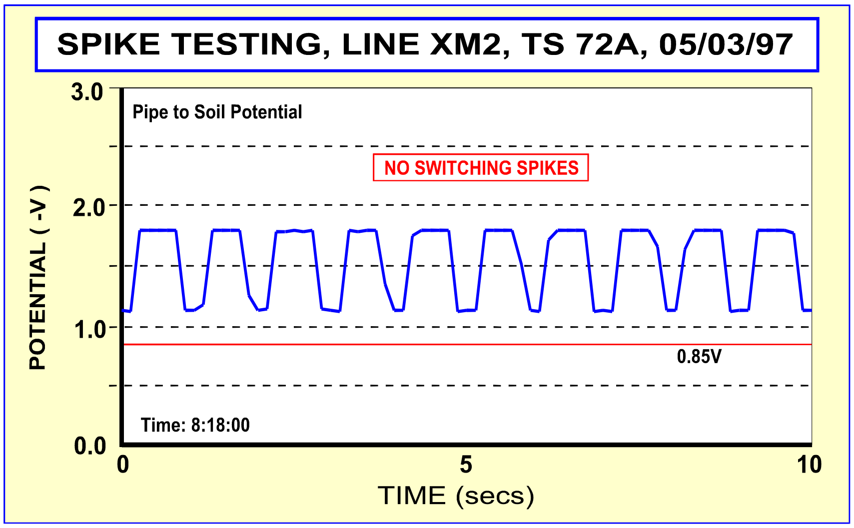
Special testing of unbonded foreign rectifier effects can be undertaken separately either before or at the end of the C.I.S.

Where bonds exist to foreign lines, it is important to know, in advance, the magnitude and polarity of the bond current with rectifiers "on" and "off".

Note that interrupting bonds may cause the current to flow in other paths, and bond interruption should only be undertaken with a full understanding of the effects. It is always far more preferable to interrupt the source(s) of the current that flow through the bond than the actual bond.

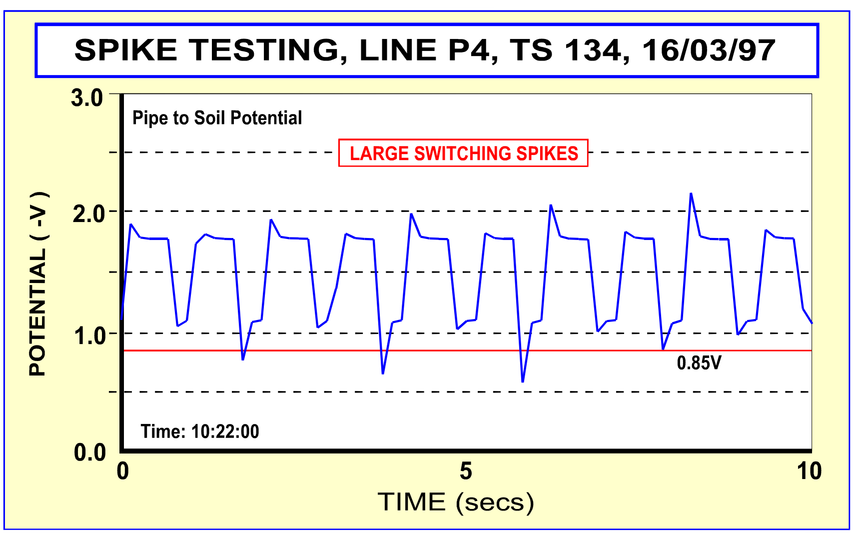
Induction Spiking – Datalogs (Waveforms)

Graph 1 shows the pipe to soil potential at a fixed location, vs time, for a coated



Graph 1

pipeline, as the line rectifiers are interrupted. The graph (datalog) shows that the transition between the "on" and "off" cycles is smooth.



Graph 2

However, on many coated pipelines "induction spiking" can occur as seen in *Graph 2*. In this graph, the switching spikes are up to 500 millivolts.

On some lines, at specific locations, these spikes can be in excess of 1000 millivolts. Their duration is normally less than 300 milliseconds, and it is extremely important that the “on” and “off” potentials are **not** recorded during this time period.

If the “on” and “off” potentials are recorded within the “spiking” window the data collected will be of little value. The datalogger must therefore be programmed to only to record the “on” and “off” potentials after the spike window.

Very occasionally, a situation will exist where the “spike window” extends beyond 1.5 seconds or even 2 seconds. Unfortunately, this situation won’t be recognized until the interrupters are installed and operating. If a long “spike window” is present, the choice is to re-program the interrupters to a longer time cycle (may take most of a day) or to continue the survey. Field experience has shown that the “spike window” is generally shorter in areas of poorer coating where the pipe to soil potentials are less negative.

Induction spikes are not generally seen on bare pipelines.

Usually three to five datalogs would be recorded during the survey day. A common time span for the datalogs would be 20 seconds. This would normally cover 10 interruption cycles at a two second cycle. At times, external sources to the pipeline and protection system may cause fluctuations, and it is always advisable to record datalogs or waveforms of such events for later analysis. Special testing of this nature may often be undertaken for 60 or 100 seconds.

Computerized Dataloggers

The dataloggers or computerized voltmeters used for C.I.S. must be capable of recording all of the required data during a C.I.S. as well as being able to withstand the survey environment.

This means that the datalogger unit must have a large memory capacity, programs designed specifically for the C.I.S., and a full alphanumeric capability in order to enter comments and notes. Internal firmware needs to be able to avoid recording data during the “spiking” that is sometimes seen during rectifier interruption and provide the operator with a range of programs specifically designed for this type of survey.

The unit must accurately record potentials (voltages) and be calibrated annually.

Pipe Location

In order to accurately record the pipeline pipe to soil potentials, it is necessary to place the reference electrodes over the pipeline.

There are various types of pipe and cable locators that can be used for the C.I.S., and their usage will depend on pipeline requirements, personal preference and experience.

Some survey crews prefer to have pipe location, distance chaining and flagging undertaken separately from the C.I.S. data collection. In this case, the technician recording the C.I.S. data follows the line of flags and makes a note of each flag as it is passed.

An alternate method involves one technician locating the pipeline immediately ahead of the data collection technician. This can be seen in *Fig 8*.

Fig 8

Normally, the pipe location would be no more than 20 to 30 feet ahead. No flagging is required, pipe location can always be verified, and the light survey wire is used for distance measuring. Having pipe location immediately ahead of the survey technician can have various benefits, particularly on bare pipelines and in farm lands where flags may not be allowed or visible. (high crops)

Auxiliary Equipment

Apart from the equipment previously described, a wire dispensing system is also required. The survey wire generally used is either an AWG #32 or AWG #34 SNLR varnish coated copper wire. This is used for maintaining constant electrical contact with the pipeline through connections made at test stations.

Distance measuring is either by chaining and flagging fixed distances, or by using the survey wire in conjunction with an electronic distance counter to measure how much wire has been dispensed. Sub-meter GPS has been used for distance measurements but various problems can be encountered.

The survey crew should also carry a variety of small spare parts, tools and tapes, in case emergency field repairs are required. A basic first aid kit should also be part of the field survey crew equipment.

Effect of Right Of way Conditions

Right of way conditions need to be noted, as should survey that has to be undertaken off line due to obstacles or uncut right of way. Sometimes, sections of line have to be temporarily skipped and surveyed later the same day or next day. All of these scenarios should be well documented by the field technician.

Fig 9

The photograph in *Fig9* above shows an ideal right of way condition where the survey technician can be directly over the pipeline for the recording of accurate pipe to soil potential data.

The photograph in *Fig 10* shows a right of way condition where the survey technician cannot be continuously over the pipeline and the recorded data may not be exactly reflective of the true pipe to soil potentials.

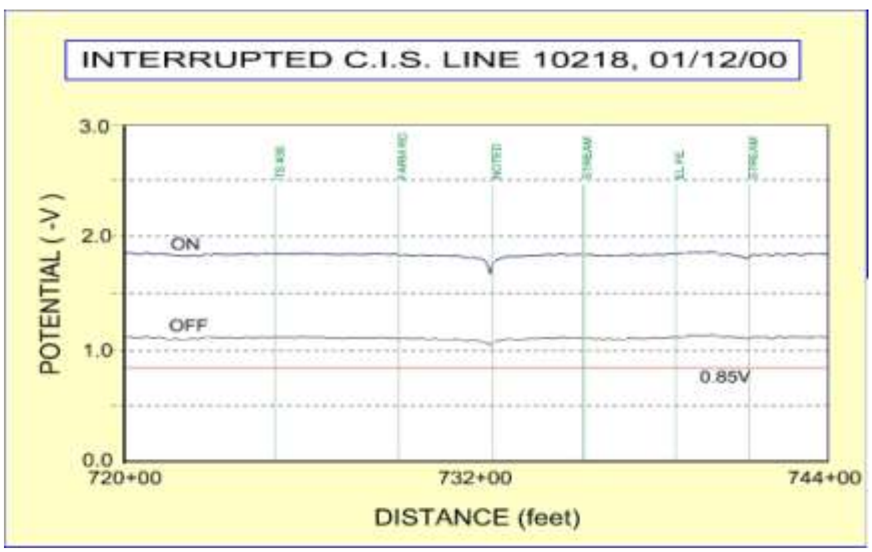
Poor right of way conditions can lead to the missing of sub-criterion pipe to soil potentials and be a safety issue for the survey personnel. Generally, on well coated pipelines, there may be very little difference between pipe to soil potentials recorded over the pipeline and those recorded perhaps 20 feet away.

The problem arises when there is a coating defect and inherently less negative pipe to soil potentials. If the survey technician is off the pipeline, the reference electrodes will produce data that are averages of larger spans of the pipeline which results in data that will be more negative than the true over-the-line potentials

Fig 10

Close Interval Survey Graphs

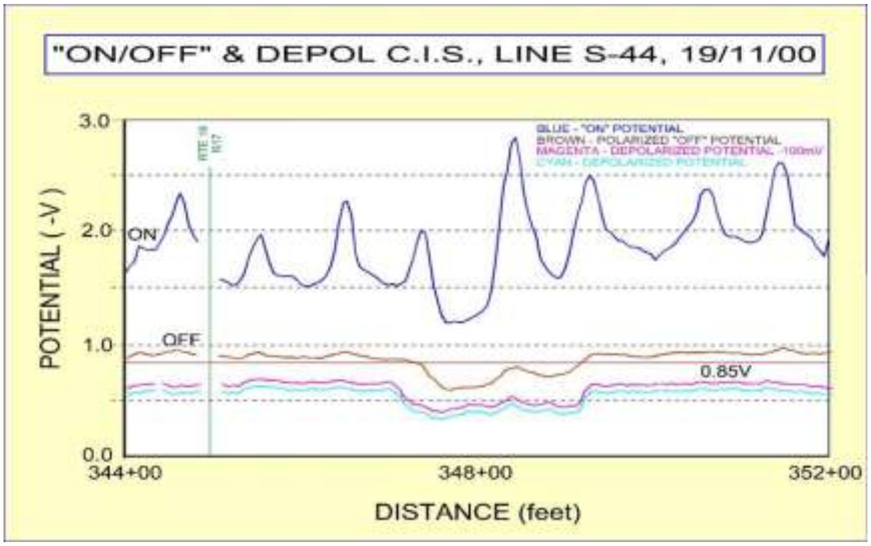
The results of the close interval potential survey are presented graphically with the pipe to soil potential plotted against distance along the pipeline.



Graph 3

A sample survey plot is shown in *Graph 3*. Generally, distance per page and voltage scale will vary according to the specification requirements.

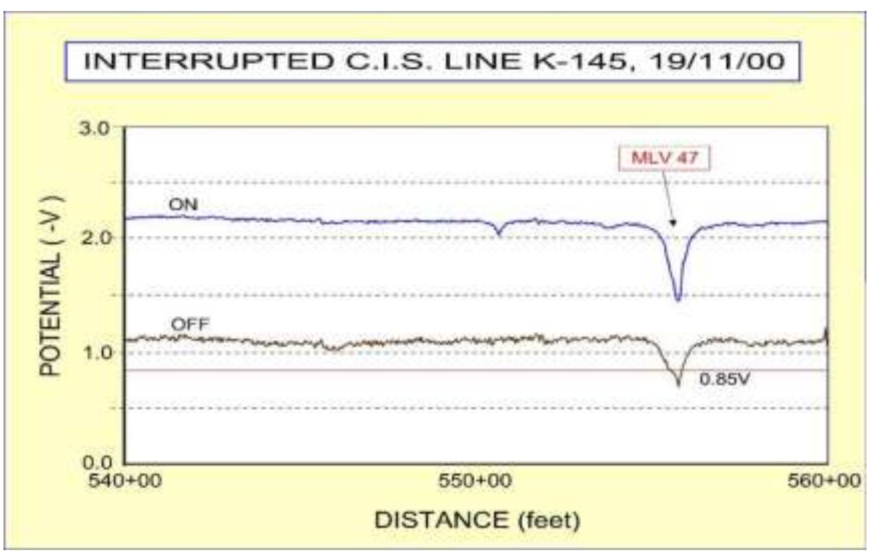
The graphs may contain additional information such as pipeline and terrain features, test station information, survey direction and other pertinent comments.



Graph 4

Graph 4 shows the results of a C.I.S. for a bare pipeline protected by distributed impressed current anodes.

While the most common criterion for adequate cathodic protection is the -0.85V polarized "off" potential criterion to the CSE, in the case of bare pipelines, the polarized "off" pipe to soil potential is more often compared to the native or depolarized potentials of the pipeline. *Graph 4* illustrates the use of the 100mV depolarization.



Graph 5

A final sample C.I.S. graph is shown in *Graph 5*. This graph typifies the type of potential profile seen when a coating defect is present.

Note that for coated pipelines, it is unlikely for the C.I.S. to identify very small coating defects. Intermediate coating defects may appear as dips in the “on” potential only, and larger defects may appear as dips in both the “on” and “off” profiles.

River Crossings

Small rivers and creek crossings may be walked through during the C.I.S. and survey data recorded through each crossing. The safety of crew personnel at any water crossing should not be taken lightly.

Larger creek and river crossings are not generally considered as part of the normal pipeline close interval survey and are most effectively undertaken as separate contracts, due to the requirement of specialized equipment and/or personnel.

Intermediate creek and river crossings may be surveyed using a small boat as shown in *Fig 11*, where a reference electrode is dragged across the river bottom over the pipeline location.

Fig 11

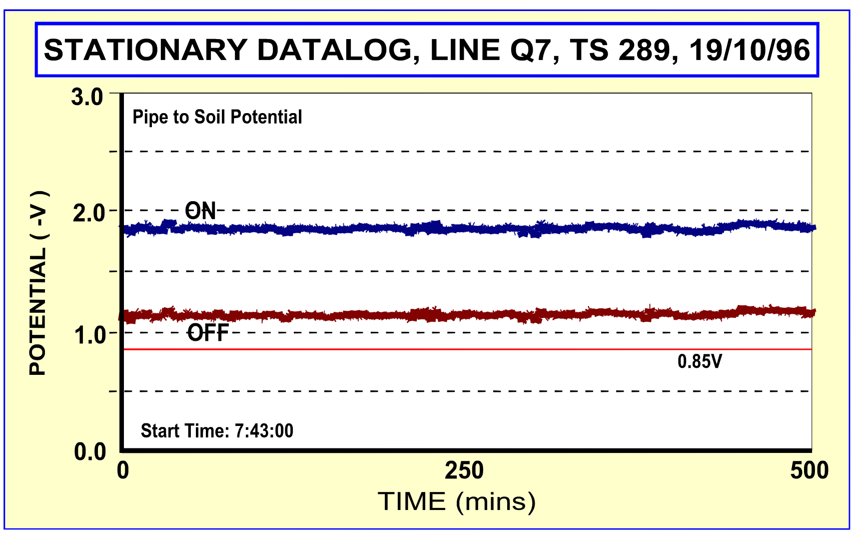
In the case of more serious river crossings, a motorized vessel with onboard GPS and professional crew may need to be utilized, as shown in *Fig 12*.

Note that if the creek or river crossing has been bored, the potential profile may be of little value as the reference electrode, even on the river bottom, may be still be a large distance from the actual pipeline.

Fig 12

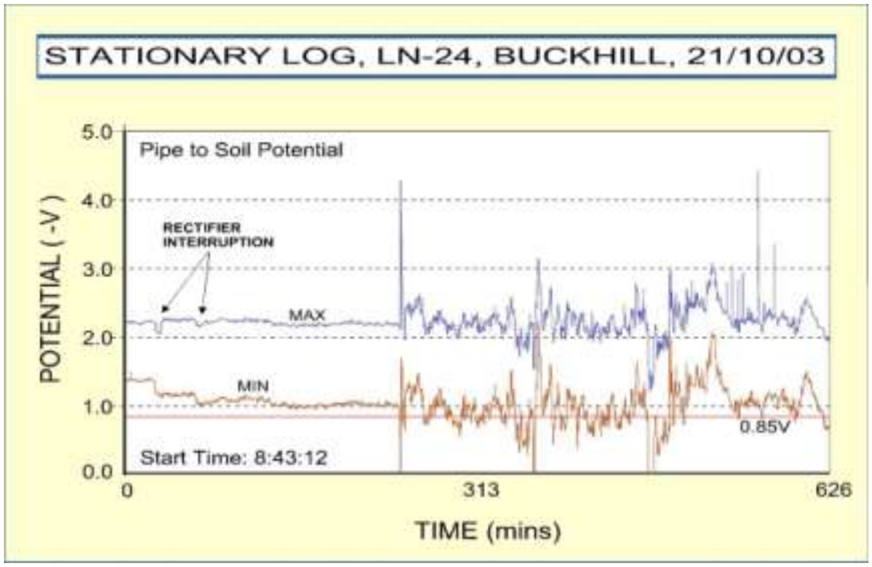
Stationary Datalogger

The stationary datalogger is a computerized voltmeter that is installed at a fixed location (usually a test station) for the whole of the survey day. The datalogger is set to record the "on" and/or "off" potentials at regular time intervals. A typical stationary log is shown in *Graph 6*.



Graph 6

The result of telluric effects on pipe to soil potentials is shown in *Graph 7*.



Graph 7

This graph is often typical of the commencement of telluric activity.

The recorded data can serve two useful functions. It can show the amount of depolarization of the pipeline and also whether the pipeline was subject to outside influences. Outside influences may be caused by other pipeline operations, telluric currents, transit system operations or other sources.

The stationary log can provide data that validates the C.I.S., provide a better understanding of the depolarization characteristics of the pipeline at a specific location and should show the effect of any short term local effects that affected the pipeline potential stability.

Test Station Data

Test Stations are normally located along the pipeline at locations such as roads, railroads, foreign line crossings and at approximately 1 mile separations in more remote areas.

The test station serves a variety of functions:

- a location where the local pipe to soil potential can be measured
- a means of electrically connecting to the pipeline
- a location where foreign pipeline tests may be undertaken
- a location where sacrificial anodes may be located
- a location where tests of casings can be made
- a location for testing buried isolating flanges
- a location where buried reference electrodes may be located
- a location where buried coupons may be tested

- a location where the voltage drop in the pipe can be measured (from the last test station)

When the C.I.S. reaches a test station, some or all of these tests may be undertaken. The data recorded will then be used in the overall assessment of the pipeline protection effectiveness.

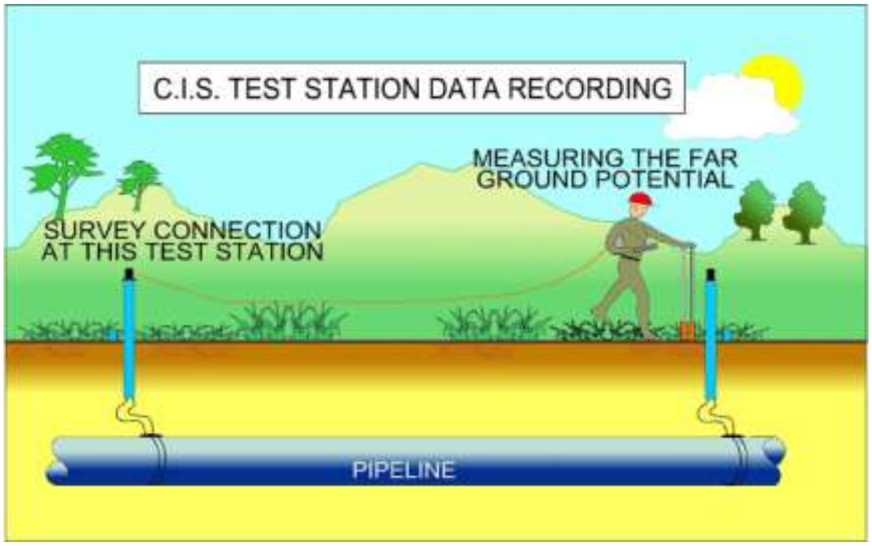


Fig 13

Probably the most important series of tests undertaken at a test station will be the recording of the “far ground” and “near ground” potentials, in conjunction with the pipe IR drop. This data is used to validate the survey through the measurement of the pipe IR drop which is directly related to the current flow in the pipeline. For an accurate interrupted C.I.S., it should be expected that the pipe IR drop will be close to zero in the “off” cycle, thus signifying that all or almost all of the current has been interrupted. Uninterrupted current will obviously effect the validity of the recorded polarized ”off” pipe to soil potentials.

Fig 13, above, shows the field technician recording the “far ground” pipe to soil potentials.

The test station is therefore a very valuable component of the cathodic protection system and a great asset for the C.I.S. Note, that in general terms, any part of the pipeline that is used for cathodic protection system testing or electrical contact, may be termed a “test station”. This would apply to valves, risers, drips and other above ground appurtenances.

Close Interval Survey Data

During the C.I.S., most of the data collected will be pipe to soil potentials. There will also be comments relating to pipeline features and terrain features as well as special tests such as datalogs or continuous logs and the data recorded at test stations, risers and other aboveground appurtenances.

Apart specifying the graphical format required for the report, the pipeline operator also needs to specify the type of format for the actual data that will be provided. This is obviously necessary so that the data can be utilized for any other purpose by the pipeline operator.

Preparations For Close Interval Potential Surveys

There are many items that need to be addressed by the pipeline operator, prior to the start of the close interval potential survey. These include the following:

1. A specification detailing the work that is required, the types of acceptable equipment and most importantly, the experience level required of the survey crew.
2. The format required for the survey report.
3. Notifications to landowners and foreign pipeline operators.
4. A right of way condition conducive to the performing of accurate surveys.
5. Pre-survey checks on all rectifiers, bonds and isolation.
6. Provision of spare fuses in all rectifiers.
7. Information on wetland and swamp locations.
8. Information on river and creek crossings
9. Access to technicians familiar with the pipeline and right of way.
10. Detailed drawings of the pipeline.
11. Historical information regarding rectifier outputs and test station data.

Summary

The intent of the close interval survey is to provide a continuous pipe to soil potential profile of the pipeline from which the integrity of the system effectiveness can be judged. The survey must record data that is technically accurate and representative of the system performance.

A poorly planned and executed survey will not only produce invalid data but can lead to erroneous conclusions, capital expenditures and a comfort level that may not exist.