Auditing of Cathodic Protection Systems and Anticorrosion Coating Conservation Status in Oil and Gas Pipelines (CIPS – DCVG Surveys)

Engineering Company in Duct Integrity

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1. Objective

To describe the procedures that take part in the Study of Cathodic Protection Systems and Coating Conservation Status for external corrosion control in underground pipelines.

2. Introduction

Corrosion in metal pipelines is an electrochemical process, caused by the generation of anodic and cathodic sites in the duct surface with subsequent direct current flow between these areas. In anodic sites, electrons are generated due to metal dissolution. These electrons travel through the pipeline steel to cathodic zones where they are consumed in reduction reactions (oxidation). Electrical circuit is completed through ionic flow in the soil between the cathodic site and the anodic site.

In order to prevent damage caused by external corrosion, pipelines are protected against these effects through a combination of dielectric coatings and cathodic protection systems. Dielectric coatings represent the first line of defense against external corrosion. Although coatings generally provide excellent protection, most of them deteriorate over time due to water absorption, ground pressures, soil abrasion, root damage, bacteriological attack and many other causes. This damage allows corrosion to occur in places where contacts are produced between corrosive environment (the soil) and steel surfaces exposed by coating faults.

Cathodic protection has the function of protecting the pipeline in places where the coating has failed, acting as the second line of defense against external corrosion. Cathodic protection is achieved through electrons supply to the metal structure, turning its potential to more negative values with regard to the environment where it occurs. By definition, corrosion represents electron loss per atom or group of atoms. When these electrons are supplied externally through pipeline steel (by cathodic protection), corrosion mechanisms are reduced to insignificant levels. These effects are complemented with the electrochemical changes in the soil (increase in pH) caused by cathodic protection application subproducts.

In the industry, at present, it is generally accepted that the combination of dielectric coatings with cathodic protection systems is the most effective measure to control external corrosion effects in underground pipelines. A less understood factor is that this control depends on a delicate balance between the physical status of the coating and the cathodic protection levels. In order to obtain effective levels of cathodic protection, pipeline potentials must be maintained between frontiers of -850 mV "off" (subprotection) and -1140 mV "off" (overprotection). This goal can only be achieved if there is a controlled fatigue in pipeline potential profile from the points of maximum potential (rectifiers or galvanic anodes) to the points of minimum potential (remote areas of rectifiers or galvanic anodes). Potential fatigue rate mainly depends on pipeline coating condition, which is considered the critical factor for the proper operation of cathodic protection systems.
The methodology used for external corrosion control in underground pipelines consists of coating inspection and effectiveness of cathodic protection to evaluate the balance between both systems. Inspections are carried out by using a combination of the techniques below:

- “Close Interval Potential Survey” (CIPS) Technique
- “Direct Current Voltage Gradient” (DCVG) Technique

It is worth mentioning that Protan S.A. has the technical assistance of Dr. John Leeds for both inspection services. Having 30 years of experience, more than 30,000 km of pipelines inspected all over the world, John Leeds is responsible for inventing and improving DCVG technique.
3. CIPS Survey

3.1 Descriptive Technical Memory

CIPS (Close Interval Potential Survey) technique is an inspection system developed for the detailed analysis of cathodic protection systems in underground pipelines. The technique consists of the continuous measurement of pipeline potentials regarding the copper/copper sulfate reference anode. The operator carries out duct routing extending a fine caliper wire from the nearest test post. The wire is connected to a pair of reference cells through a field computer. The reference cells are located in turn lying on the ground while the operator moves along the pipeline and the field computer records potential values.

The pipeline potentials are recorded with switched on current (“on” potentials) and with switched off current (“off” potentials) to eliminate “IR” errors in measurements caused by current flow between the pipeline and the reference cells. In order to obtain “off” potentials, cyclic timers are placed in all the cathodic protection sources having influence on the zone under study. Timers must work in perfect synchronization to allow “off” potentials accurate measurements.

Results of CIPS studies serve the purposes below:

(a) Identification of pipeline protection levels:
CIPS graphs of “off” potentials profile help to identify pipeline polarization levels accurately. “Off” potentials must be maintained between subprotection frontier (-850 mV) and overprotection frontier (-1140 mV).
“Off” potentials below -850 mV suggest insufficient polarization of the pipeline steel, which can allow pipeline corrosion. “Off” potentials above -1140 mV suggest excessive polarization of the pipeline steel, which can be harmful for the pipeline coating due to the effects of cathodic disbondment.

(b) Estimation of the pipeline coating status:
“On” potentials profile is a useful tool for the evaluation of the pipeline coating status. In zones with good quality coating, potential profile stays mainly stable and there will be a constant difference between “on-off” potential profiles. In zones where there are defects in pipeline coating, valleys will be recorded in the potential profile, valley sizes being proportional to fault seriousness. In addition to this, there will be a reduction in the difference between “on-off” potential profiles.
(c) Identification of zones with possible electrical interference:
An additional function of CIPS technique is the detection of pipeline zones affected by possible electrical interference, particularly direct current interference associated with current charges and discharges through the soil from or to foreign duct systems. Current charge zones show significant increases both in “on” potential profile and in “off” potential profile, without any significant changes in the difference between both profiles. Similarly, current discharge zones show unusual reductions in both potential profiles with a constant difference between both profiles.

To sum up, CIPS technique achieves the functions below:

(a) Identification of zones with inadequate cathodic protection levels.
(b) Identification of zones with excessive cathodic protection levels.
(c) Identification of zones with possible defects in coating quality.
(d) Identification of zones affected by possible electrical interference.
3.2 Work Procedure

CIPS survey process is conformed by the stages below:

1) Preliminary study of the pipeline to be inspected
It includes location and design analysis of the pipeline to be inspected; CMP identification, rectifier equipment, ERP, valves, derivations, road crossings, etc.

2) Pipeline layout signposting
Pipeline layout is signposted with stakes placed every 30 m using a pipeline detector.

3) Intervention of rectifier equipments
At this stage the installation of satellite synchronized interrupters (timers) is carried out over the rectifier equipments that may affect the zone to be inspected. Interruption cycles of the timers conform a determined on/off relationship to avoid significant depolarization of the pipeline during the course of the studies.

In order to confirm timer synchronization a digital oscilloscope is used, comparing waveforms and verifying if any timer is out of synchronization in each of the kilometric benchmarks.

4) ON-OFF potential assessment
Once the intervention of rectifier equipments has been carried out, On-Off potentials are recorded along the pipeline using a data storage equipment (data logger). The steps included during potential assessment are described below:

a) Measurements are carried out over the pipeline layout with a separation distance equal to one meter (1m) between two consecutive measurements.

b) In those cases where the work zone has dry soil, the contact point between the CU-CUS04 electrodes and the soil will be humidified.

c) All assessed measurements will be set to the benchmarks (CMP) or other reference points considered by the company.

d) In case of obtaining Off potential readings more positive than -850 mV, or identifying zones with significant drops in the least negative sense; a potential measurement will be taken on the right and/or left side of the pipeline.

e) All crossings with pipelines belonging to a third party will be analyzed, which will be referenced and, if possible, measurements of their potentials will be taken.

f) Before connecting the equipment to a new measurement post (CMP), close link data and IP drop will be recorded.

 g) All those structures that are located in the vicinity of the pipeline layout will be recorded as references.

h) The cable used during the inspection and the stakes of the pipeline layout signposting will be collected.
5) **Evaluation of insulating joint operation**
Potentials in both sides of the insulating joints will be recorded in order to verify their proper operation.

6) **Localization of contacts with structures**
Casing pipeline potentials will be recorded in the data collector, and in case it is in contact with the pipeline, it will appear as such for future repairs.

7) **Detection of Electrical interference**
Potentials with cross lines external to the study will be recorded and potentials will be taken on them if it is possible. Measurements will also be taken in zones close to industries, transforming equipment, crossings of high and medium tension lines, railway systems, etc.

8) **Data download in sofware**
After finishing the field work, data must be exported from the data recorder to the sofware destined to the analysis of the information (See item 6).

9) **Analysis of assessed information**
Though the use of sofware, an electrical profile of the whole pipeline in question is obtained, represented through an easy-to-interpret graph of electric potentials according to the distance covered.

The graph shows the behavior of On (in blue) and Off (in red) electric potentials along the pathway in question. For a better understanding of the information, pathways of approximately 1 km of distance are established, demarcated by two consecutive measurement posts (CMP).
In the X-axis progressive distances related to each pathway are expressed, indicated every 100 meters of distance with the objective of facilitating identification of particular zones.

Physical references along the whole analyzed pathway are represented through a vertically-aligned text into the graph field, positioned in real progressive. Thus, other reference points can be considered without the need to refer to the beginning of the study, reducing the error of superficial measurements when marking a defect in the coating.

Finally, the graph has a dotted line with a constant value of -850 mV that is used as a reference of the protection and polarization levels regarding the limit accepted by NAG-100.
4. DCVG Survey

4.1 Descriptive Technical Memory

“Direct Current Voltage Gradient” (DCVG) technique is a system developed for the detection and analysis of defects in underground pipeline coating. Defects are localized by examining potential gradients in the soil covering the pipelines to determine the direction of cathodic protection current flows.

Since cathodic protection acts in a current flow towards the steel points exposed in the pipeline, defects in the coating can be located individually. The high sensitivity of DCVG instruments allow even the smallest defects to be located with an accuracy of about 10 cm.

Once the defect has been located, its importance is determined considering the four parameters below:

(a) Defect size:
Defect size is determined by measuring the potential loss between defect epicenter and remote earth. This value is expressed as a fraction of the pipeline potential change (the increase in potential due to cathodic protection application) to calculate the so-called IR value. The defects are assigned to the following four categories according to their respective IR values:

**Category 1 (51-100 % IR)**
Category 1 coating defects are considered critical since the high size of steel exposed to the soil prevents adequate operation of the cathodic protection systems, increasing corrosion risks. The inevitable current consumption related to these defects also prevent adequate protection in most remote zones regarding cathodic protection supply points.

**Category 2 (36-50 % IR)**
Category 2 coating defects represent large steel areas in contact with the soil. These defects generate high consumption rates of cathodic protection currents and prevents a good current distribution from the cathodic protection supply points.

**Category 3 (16-35 % IR)**
Category 3 coating defects represent medium steel areas in contact with the soil causing moderate consumption rates of cathodic protection currents.

**Category 4 (0-15 % IR)**
Category 4 coating defects are considered trivial, as these seem to have a minor impact on the cathodic protection system.
Category 4 coating defects represent small steel areas in contact with the soil. Defects are considered less important since cathodic protection systems can provide long-term protection to these points.

It is important to emphasize that % IR estimations are not always directly related to the physical sizes of coating defects. There are cases where the application of cathodic protection generates layers of calcareous and/or magnetite deposits over the steel surfaces exposed as a result of coating defects. These layers show a high resistance to the cathodic protection circuit and act as a secondary coating for pipeline protection. In these cases, % IR estimations consider both “coatings” and the physical sizes of the defects to be lower than the ones anticipated. In other cases where there are low cathodic protection levels and/or presence of acidic soil that inhibits the formation of calcareous layers, the physical sizes of the defects are greater than the ones anticipated.

(a) Defect length:
Operators experienced in DCVG system can determine the approximate length of coating defects by examining the potential gradients around them. This data provides critical information regarding excavation length and quantity of materials and resources necessary to carry out the repairs.

(b) Defect corrosion status:
DCVG provides additional information regarding corrosion status of each defect. It was previously mentioned that this technique is capable of determining the direction of the current flow on the soil by covering the ducts. Since corrosion results in current flow from the defects and cathodic protection results in flow towards the defects, it is possible to determine the corrosion status of each defect individually. DCVG application is particularly useful during galvanic anode detection.

(c) Defect influence regarding electrical interference:
Operators experienced in DCVG system can conduct electrical interference surveys from foreign ducts as well as towards foreign ducts. Interference from foreign ducts will record anodic signals in our own pipeline. Interference towards foreign ducts will record anodic signals in the foreign pipeline. DCVG system also represents an agile tool for detection and determination of parasite current flows in the soil between our own pipeline and the foreign pipeline.

To sum up, DCVG technique accomplishes the functions below:

(a) Accurate defect detection in duct coating.
(b) Defect size evaluation.
(c) Defect length evaluation.
(d) Current corrosion status evaluation in steel exposed by defects.
(e) Galvanic anode detection.
(f) Survey of zones with possible electrical interference.
4.2 Work procedure

DCVG assessment process is composed by the stages below:

1) **Pre-Assessment of pipeline to be inspected**
   It involves the location and layout of the pipeline to be surveyed; CMP identification, rectifier equipment; ERP, valves, derivations, crossroads, etc.

2) **Pipeline layout signposting**
   The pipeline layout is signposted with stakes placed every 30 m using a pipeline detector.

3) **Intervention of rectifier equipments**
   At this stage the installation of satellite synchronized interrupters (timers) is carried out over the rectifier equipments that affect the zone to be surveyed. Interruption cycles of the timers conform a determined on/off relationship to avoid significant pipeline depolarization during the studies.

   In order to confirm timer synchronization, a digital oscilloscope is used, which compares waveforms and verifies if any timer is out of synchronization in each of the kilometric benchmarks.

4) **DCVG Survey**
   The pipeline is assessed using DCVG Potential Gradient Meter. The use of this instrument allows to obtain the information below:

   a) Coating fault epicenter location with an accuracy of 10 cm.

   b) Determination of size, shape and severity of each defect.

   c) Classification of each defect according to corrosion behaviour, enabling the identification of those defects that do not have sufficient cathodic protection and may result in metal loss.

   d) Identification of zones with presence of electrical interference through those defects that are receiving or discharging continuous current.

   e) Identification of origin of the Cathodic Protection current that acts on each defect, aiming at determining if it is possible that a defect .... unprotected due to the wrong operation of a Cathodic protection source.

   f) Identification of third party pipelines or structures that interfere and benefit from the Cathodic Protection system.

   g) Determination of dielectric joint status.

   h) Identification of defects located in Potential Measurement Boxes (CMP), used for high-frequency potential measurements.
Determination of the severity of each defect is expressed through percentage IR. This is calculated by considering the relationship between the potential drop in the fault and a value taken at remote distance.

Location of each defect is established through geographic coordinates, partial progressive distance (from CMP), total progressive distance and depth. Besides, a stake is placed over each defect location point to facilitate identification while carrying out repair.

5) Data download in sofware
After finishing field work, all data must be exported to the sofware destined to the analysis of the information (See item 6).

6) Analysis of assessed information
By using sofware, surveyed information is analyzed and coating conservation status is determined.

Software allows to generate graphs that show defect concentration during the survey. At the same time, it allows to group defects according to their condition (Cathodic – Cathodic; Cathodic – Anodic; Anodic – Anodic) or according to percentage IR.

Through these graphs, it is determined which zones are the most at risk and which are the defects that need immediate and/or medium term repair.

Almost accurate localization of the defect, its shape and status, allow to establish defect repair programs with a significant decrease in excavation costs.
5. List of equipment and instruments used

- Quantum Data Logger, manufactured by DC Voltage Gradient Technology & Supply Ltd.

- DCVG Potential Gradient Meter, manufactured by DC Voltage Gradient Technology & Supply Ltd.

- Synchronized Interrupters EPIGPS20, manufactured by Epca+Imastec.

- Amprobe R-3000 PRO Pipeline localizer

- Portable rectifier equipment 50 V – 50 A

- FLUKE 189 Digital Multimeter

- Fluke Oscilloscope Scope Meter

- Garmin GPS 76 Satellite Navigator

6. CIPS & DCVG software description

CIPS & DCVG software is a computer tool …… to the analysis of the information surveyed in the field work. Developed by DC Voltage Gradient Technology & Supply Ltd., the software allows loading of data generated in both types of survey.

Among the most outstanding aspects of the software we can mention the integrated analysis of CIPS & DCVG data. Through the generation of different types of graphs, we can evaluate the influence of the defects in the coating on the cathodic protection levels. Besides, it allows to carry out corrections in IR values of defects localized in DCVG survey with information surveyed in CIPS survey.

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