Out with the old

[AND IN WITH THE NEW!]

{Christophe Baeté, Project Manager, Elsyca, Belgium, examines a novel approach for cost-effective cathodic protection surveys.}

Today's operators continue to face challenges in gathering quality cathodic protection (CP) data. Most operators employ indirect methods such as potential and coating survey techniques to monitor CP effectiveness. However, gathering the data is time consuming and expensive, especially when the pipe is located in an area of difficult access or external influences interfere on the measurements. Monitoring the CP effectiveness and identifying protection problems can be cost-effectively performed with a new

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Modelling technology allows upfront optimisation of the CP system and ensures highly efficient and low cost protection of pipeline structures. A properly working CP system requires an understanding of the behaviour of the electrical and electrochemical process performance in terms of current and potential distributions on the pipeline system and in the soil. In the field, the CP currents that should reduce corrosion to acceptable levels are not usually measured and the pipeline condition is assessed indirectly by potential measurements.

The major parameters determining the effectiveness of a given CP system (with fixed geometry and anode configuration) are:

- Coating quality.
- Soil resistivity.
- Structure polarisation.

These parameters can vary along the structure, which complicates the design of the CP system and its monitoring. Modelling technology allows visualisation of the CP current density and the pipe-to-soil potential distribution on the structure whatever the complexity of the pipeline network.

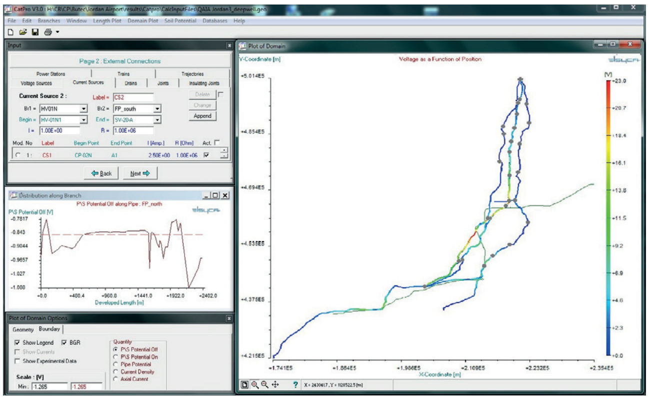

Figure 1. Elsyca's CatPro software interface.

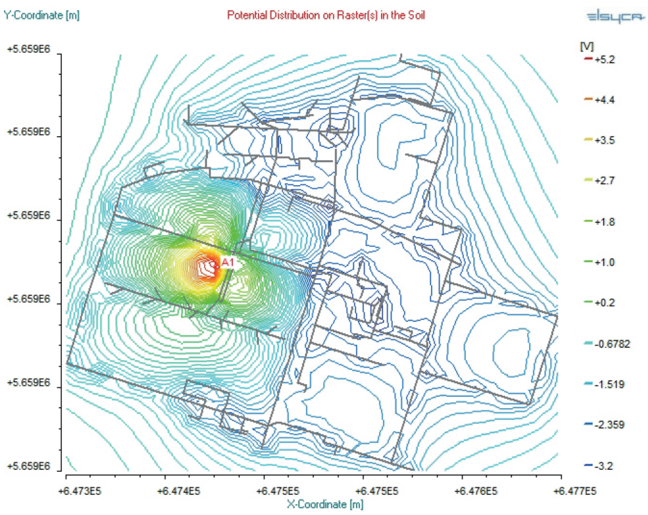

Figure 2. Example of Elsyca's CatPro calculated ON potentials at grade level.

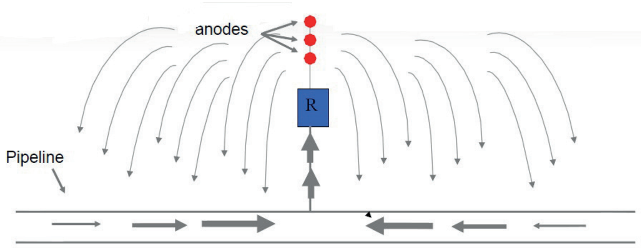

Figure 3. Current flows in typical CP system.

Limits of conventional CP surveys

The aim of a CP system is to obtain a structure-to-soil or IR-free (IR = ohmic drop) potential on the entire structure that is more negative than a certain minimum protection level but on the other hand not too negative in order to avoid excessive hydrogen formation that leads to coating disbondment and increased risk of stress corrosion cracking. This IR-free potential can only be measured with a reference electrode that is placed directly adjacent to the structure in order to reduce the IR drop in the electrolyte. In practice this is nearly impossible due to the hidden nature of the structure. Conventional pipeline surveys are therefore limited to ON and OFF potentials taken at the earth grade.

The OFF potential is measured by interrupting the rectifiers and measuring the instant pipe-to-soil potential before depolarisation starts. This measuring technique rules out the IR drop, but only on condition that no stray current interference or other discharging currents are present. In addition, it can be difficult to switch off all CP systems that are delivering protective current to the structure. In the case of sacrificial anodes, no OFF potentials can be obtained unless the anodes are disconnected. A small amount of current will still be flowing to the structure leading to a potential drop in the electrolyte and thus causing an error in the potential reading.

Potentials are measured at test points or at locations where there is a direct access to the pipe. In a more intensive form close potential surveys (CIPS) can be performed. Potential readings are combined with coating surveys such as direct current voltage gradient (DCVG) or alternating current voltage gradient (ACVG) in order to assess the severity of corrosion attack as it is usually performed in external corrosion direct assessment (ECDA) programmes. Executing ECDA programmes is labour intensive and costly and does not always give reliable results as is evident in congested areas, or for complex installations, or pipelines under AC or DC interference.

Figure 4. CPCM™ tool (courtesy of Baker Hughes).

It is very important to have an adequate model that describes the performances of the cathodic protection system and the real pipeline behaviour. In this article, a powerful modelling software tool is discussed that simulates the electrical/electrochemical processes occurring at the pipe metal surface based on the current flowing into the pipe wall. This current value is acquired by an ILI tool.

Modelling cathodic protection

The real protection level of a structure can be obtained through modelling since measuring errors or interference problems only occur in the field. A CP system and pipeline can be represented as an electrical network. The current and voltage output of the rectifier is determined by the characteristics of this electrical network. The voltage of the rectifier is determined by the total resistance of the network and the current flowing through it. The main resistive components are the soil and the coating resistance, which can vary locally resulting in different current densities and protection potentials at the pipe metal surface.

Elsyca's CatPro software is a BEM/FEM-based computational tool that allows simulating the behaviour of a cathodic protected pipeline. A model of the pipeline network and the CP system is built including insulating flanges, groundings, joints, anode beds, connection cables and rectifiers. In case of DC and AC interference, the rail track and HVAC line route can be included. At the pipe metal surface current density reaching the pipe will polarise the pipe to a certain extent and this is dictated by the polarisation curve of steel for a specific soil.

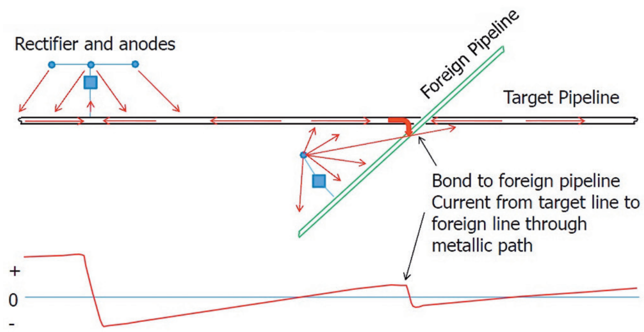

Figure 5. Typical axial current profile in presence of bond to foreign pipeline.

The entire pipe is divided into discrete sections to which different properties such as coating condition or soil resistivity can be addressed. Under normal usage the rectifier current output, coating resistance, soil resistivity and pipe-to-soil polarisation behaviour is given. Operational data and pipeline characteristics are gathered from surveys or extracted from pipeline integrity management systems.

The CatPro software calculates:

- IR-free potentials at the pipe-to-soil interface over the full pipeline trajectory.
- ON and OFF potentials at different soil grade levels.
- Axial current flow in the pipe wall.
- Local current density.
- Rectifier voltage.

In the software simulation results can be compared to experimental field data, which is useful for troubleshooting CP anomalies.

Once the model is in place different 'what if' scenarios can be investigated, as example:

- Effect of future pipeline extensions and modifications.
- Influence of rectifier settings or failures.
- Long-term coating degradation.
- Changes in soil resistivity.
- Effect of bonds and shorted insulating flanges.

Figure 6. Google Earth representation of pipeline route.

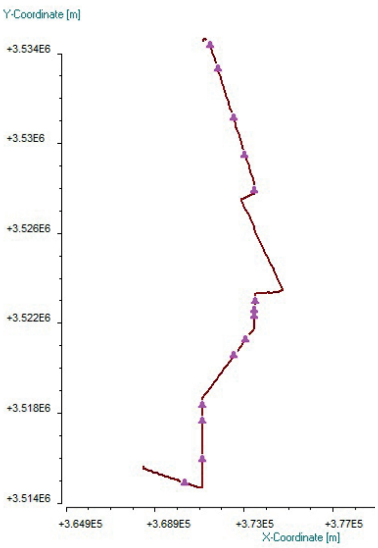

Figure 7. Corresponding CatPro simulation model of pipeline.

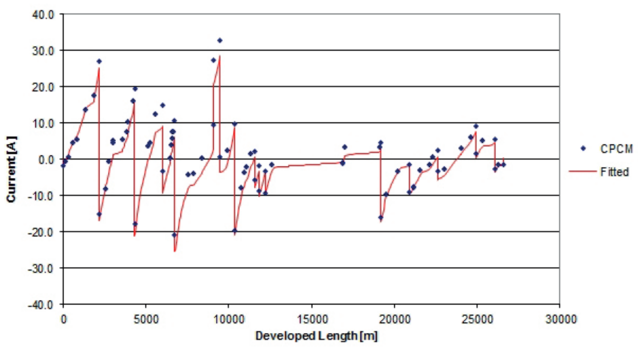

Figure 8. Axial current in function of pipe chainage: simulation and CPCM results.

- Impact of DC and AC interference.

As an example, the ON potential at grade level of a poorly protected chemical plant piping system with centralised anode bed is shown in Figure 2.

Current never lies

A CP system is an electrically closed circuit. The CP current flows from the anodes into the soil towards the pipeline, enters the pipe at coating faults, travels along the pipe wall (axial current flow) and leaves the pipe at the connection cable with the rectifier or sacrificial anode. Figure 3 shows a typical current flow in the CP electrical network. The applied current can be deviated if the pipeline is electrically connected to foreign structures by (undesirable) shorts or bonds. The current is collected at the connection cable between the rectifier and pipe and has a sign that depends on the direction where it comes from.

Since there must be continuity of current flow in the CP circuit, measuring this current flow in the pipe wall will determine exactly how much current the pipe receives from the CP system or third party systems in the inspected section.

The current flowing to the pipe wall (axial current flow) can be measured by the ILI tool from Baker Hughes. The cathodic protection current mapper (CPCM™) inspects piggeable pipeline sections during normal pipeline and CP operation (Figure 4). The CPCM tool measures accurately the potential drop over the pipe wall at a speed of a few miles per hour. The potential drop is converted to axial current flow through Ohm's law E = IR.

A typical axial current flow profile with different drain/source sections is given in Figure 5. The results from a CPCM inspection have the same value as a combined CIPS and coating survey with the difference that data is obtained faster, more accurately and easier (no problems with access, permissions, etc.). The tool is able to:

- Determine the local current density.
- Verify the current output of the rectifiers.
- Detect the location of bonds and short in the pipeline that leads to current loss or current gain.
- Detect AC and DC interference.

The CPCM technology does not provide pipe potentials that are required by national and international standards to assess the protection level of the pipeline. The modelling technology, however, does provide this data and hence the idea to combine both technologies has resulted in a very powerful tool for the assessment of the CP efficiency. This new approach is promising since the NACE RP-0169 standard allows latitude for the operator in the use of any method as long as it provides at least the same level of assurance. This new approach was validated on a crude oil pipeline.

Case study

An old 8 in. pipeline with an approximate length of 16 miles (26 km) was investigated by the CPCM tool. The majority of the line has a coal tar coating except for three re-route sections that are coated with fusion-bonded epoxy (FBE). In total,

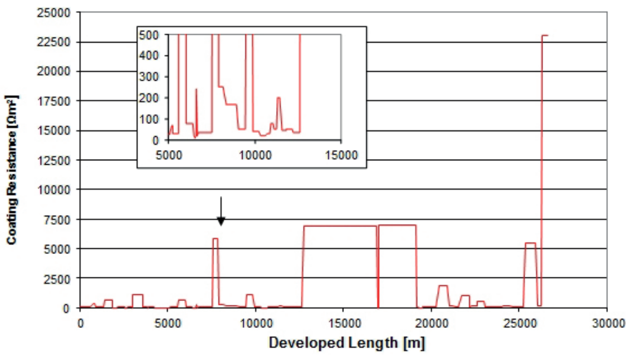

Figure 9. Simulated coating resistance with zoom in of coal tar coating sections.

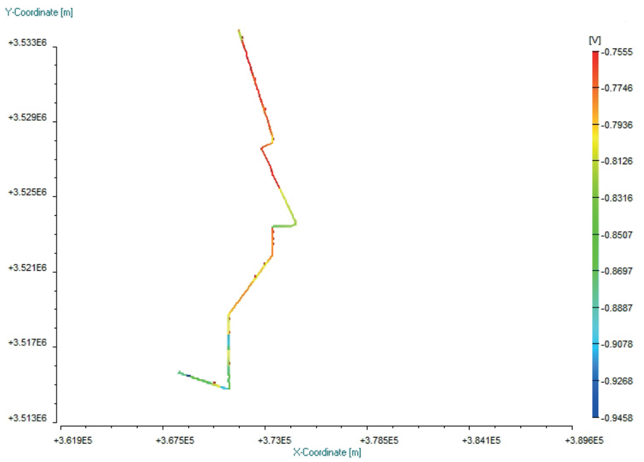

Figure 10. Plot of the simulated IR-free potential of the pipe – potential OFF as a function of position.

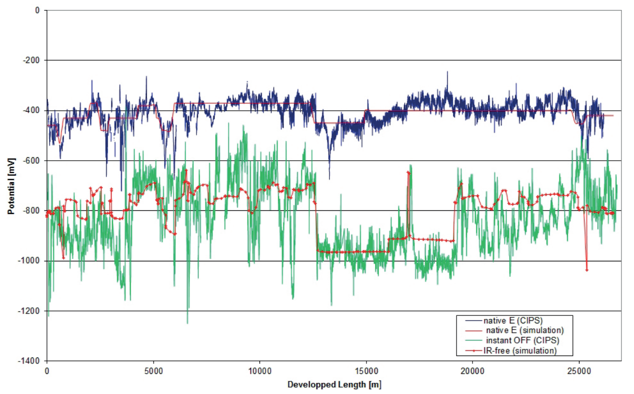

Figure 11. Comparison between simulated potentials and CIPS survey data.

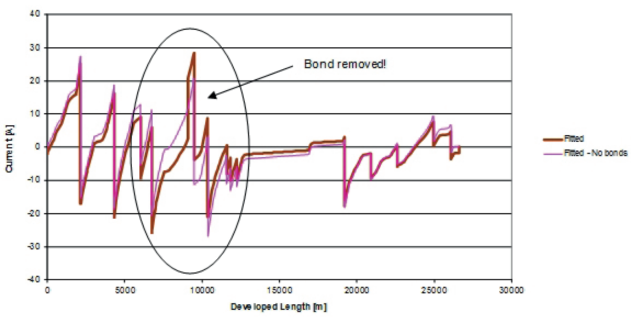

Figure 12. Effect of disconnecting a bond between pipes.

12 rectifiers are protecting the pipeline with a total current output of 236 A.

The CPCM tool took 11 hours to measure the complete pipe, which means an inspection speed of 1.5 mph (2.4 km/hr). In total 61 drain/source sections were identified based on the typical axial current profiles (see Figure 3). For each section the current density was calculated and ranged widely from 0.014 - 13.03 mA/ft^2 with an average value of 1.33 mA/ft^2 or 14 mA/m^2. Summation of the currents per section revealed a total current of 245 A. The difference was due to current intake from third party CP systems at three different locations.

The axial current data from the CPCM tool was used in Elsyca CatPro simulations to calculate all relevant CP parameters such as IR-free potential, coating resistivity and ON/OFF potentials at earth grade.

A Elsyca CatPro simulation model was built based on the XY co-ordinates of the pipelines. The exact position of the anode beds was not given but could be estimated based on the CPCM data. The three bonds to foreign structures were also included in the model. Figure 7 shows the simulation model of the pipe route with rectifier positions (pink triangles). The current output of the different rectifiers and the soil resistivity (reported to be between 50 and 100 Ωm) was entered as input data. The axial current data from the CPCM tool was used to fit the coating condition in the model. Figure 8 gives the comparison between the measured and simulated axial currents.

The simulated coating resistance after fitting is given in Figure 9. Sections with new FBE re-routes are clearly seen showing values exceeding 5000 Ωm^2. The built-in graph is a detail of the coal tar coating showing sections that have coating resistance below 250 Ωm^2. This region, for example, can be prioritised for detailed field coating survey.

The simulated OFF potentials at grade level are visualised in Figure 10. The simulation results indicate that the pipeline has IR-free potentials ranging between -0.905 and -1.049 V_{CSE}, indicating proper protection. However, a fixed polarisation data was used for the entire pipe. The native soil potentials were measured in the field by leaving the pipe depolarised (no CP) for several days. The native potentials were relative positive as can be seen in Figure 11. The data was used to refine the polarisation curve for the individual pipeline sections in the model. The new simulations showed less negative IR-free potentials. This was confirmed by a CIPS survey. The simulation results (purple line) are plotted against the CIPS survey data (green line). The difference between the native and simulated IR-free potential indicates that the current of the rectifier can be reduced for some parts of the pipeline (e.g. FBE-coated section between 12 000 and 18 000 m) if the 100 mV criteria is used.

Note that CIPS surveys have been performed in this case but this intensive effort is not required to validate the model. The modelling results can alternatively be checked by measuring potentials at some test stations along the pipe route.

Once the model is in place and validated, different 'what if' scenarios can be studied. Whatever changes that are occurring, the effect on the protection level of the pipeline can be predicted up-front through simulations. For example, Figure 12 shows the simulated axial current flow in the pipe wall for the situation with and without a bond to a foreign pipeline. Other influences, such as the effect of ageing of the coating, rectifier failure, adding new pipelines, varying soil resistivities, etc., on the protection level of the pipeline can easily be predicted through simulation.

Conclusion

A new approach is presented for assessing the CP efficiency of large pipeline networks and it consists of combining Elsyca's modelling technology with the Baker Hughes ILI tool.

Long pipeline sections are automatically inspected in a single run and at considerable speed (few miles per hour). The local current flow in the pipeline is measured during the passage of the pig and these measurements are translated by Elsyca's CatPro modelling software into values for the most relevant CP parameters such as current density, pipe-to-soil potentials and coating resistance. This new approach is much less affected by errors as is the case with field measurements.

This allows pipeline operators to assess the external condition of the pipeline in a cost-effective and accurate way with a minimum of effort. After the first analysis, the actual protection level of the full pipeline system is known at actual status. The simulation model can then be used to predict the impact of possible changes in the system on the protection level of the pipeline. Monitoring of the CP system performance can easily be achieved by comparing simulation results with field data from a new inspection run with the CPCM tool. WP