STARTED FROM THE BOTTOM

Christophe Baeté, Elsyca nv, Belgium, Len Krissa and Alfonso Garcia, Enbridge Pipelines Inc., Canada, outline the 3D bottom-up approach applied by mechanistic modelling for pipeline integrity management.

Pipeline integrity management software programs (PIMS) generally rely on statistical correlations between big data collected over many years of pipeline operation. However, with respect to corrosion assessment, the 'devil sits in the details' and corrosion rates are difficult to monitor directly, which often results in post-mortem assessment by inline inspection (ILI) tools. This is not the case when using mechanistic modelling.

Modelling

Mechanistic modelling applies a 3D bottom-up approach. Through mechanistic modelling, the cathodic protection (CP) current and AC and DC interference current are computed in a 3D soil environment. The current distribution is determined by the coating condition and the soil corrosivity (current demand of bare steel), and once known, the corrosion rate is calculated at each coating defect predicated from the ILI corrosion anomalies identified on pipelines. As such, the ongoing corrosion process at coating defects is identified and can be monitored. To obtain quantitative results, conventional field data that has been collected at grade is used to calibrate the mechanistic models for the unknown parameters such as the coating condition. Once calibrated, output from the mechanistic model can be leveraged, offering added value to ECDA field data by providing IR-free potentials, current densities and corrosion rates along the pipeline. Obtaining corrosion rates is very valuable for timely detection of detrimental events, identifying root causes of corrosion anomalies, interpreting RMU alarms, finding inconsistencies in the survey data, and monitoring the accumulated metal loss over time for integrity assessment at the uppermost level.

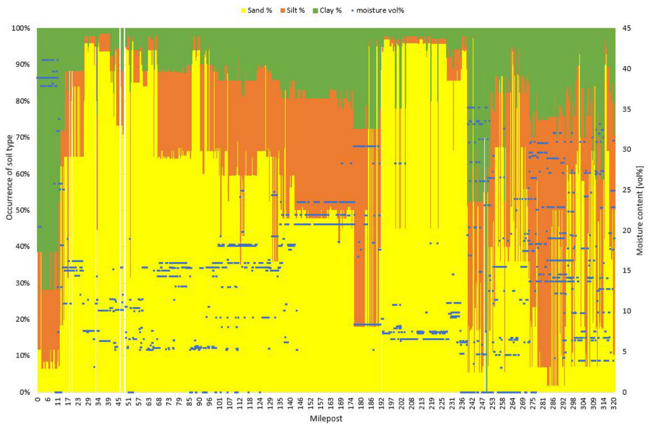

Figure 1. Soil properties along the pipeline corridor.

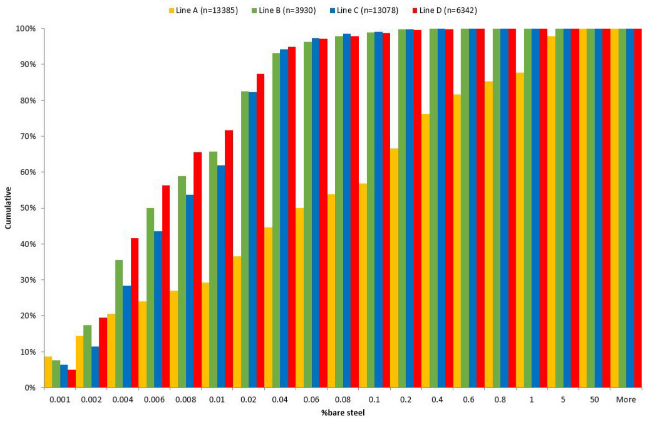

Figure 2. Distribution of the percentage bare steel.

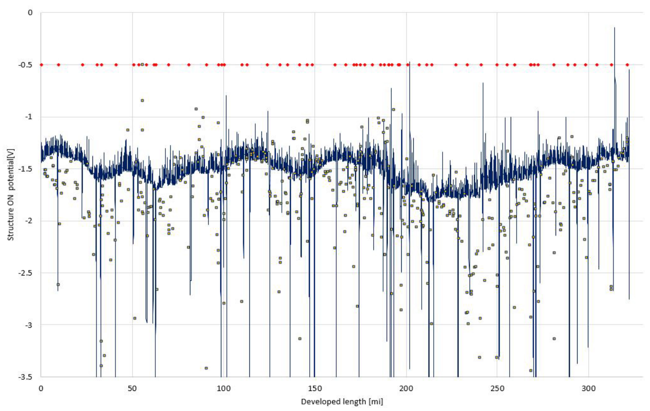

Figure 3. Simulated (line) and measured (squares) PSP ON with rectifier locations (diamonds).

Leveraging field data

A case study is discussed on a 320 mile long corridor consisting of four parallel pipelines sharing the same CP system (60 rectifiers in total) and being in collocation with high voltage AC power lines (56 in total). Accidental shorts may exist with casings (264 in total) and the neutrals at motorised valves (31 in total). The total steel surface to be protected is approximately 5 million m^2. The mechanistic model was prepared in the GIS based Elsyca V-PIMS software platform, and enabled bridging pipeline operating data with corrosion anomalies.

The pipelines cross 15 different soil types, for which the soil physico-chemical properties are extracted from the Web Soil Survey operated from USDA Natural Resources Conservation Service (NRCS). The soil properties are attributed to the 2935 different pipeline sections that consist of one or more pipe joints. As an example, soil texture (sand/silt/clay) and moisture content are leveraged to the soil corrosivity and current demand of bare steel.

ILI data was investigated to the dimensions of the anomalies used to estimate the area of exposed steel on each joint. Figure 2 provides the distribution of the percentage bare steel for each joint showing corrosion anomaly features. Line 1 is a vintage PE tape/coal tar coated pipeline, while the other pipelines have a fusion-bonded epoxy (FBE) coating. Most of the coating defects are small for the newer FBE coating, resulting in a percentage of bare steel below 0.04%, while for the older PE tape/coal tar coating it has the largest coating defects, resulting in 5% bare steel for most of the corroded joints. The percentage of bare steel and size of the coating defects result in coating resistance that will influence the current demand of the CP system. It must be noted that the mechanistic model revealed the coating resistance was overestimated for the PE tape/coal tar coating and corrosion anomalies could not be associated with open coating defects. Imposing the rectifier current in the model caused pipe-to-soil potentials that were far more electronegative than the survey readings, indicating CP shielding effects and corrosion under disbonded coating.

The total current consumed by the pipeline corridor was 403 A ±78. The current output of each rectifier was imposed in the mechanistic model, and the coating resistance and accidental current leaks were further refined based on the pipe-to-soil ON potential measurements. After calibration, the model provides the IR-free potential, current density and corrosion rates along the pipelines.

The AC interference level of the pipeline is simulated by introducing the 56 power lines in the mechanistic model. The power line properties are calibrated based on the measured AC

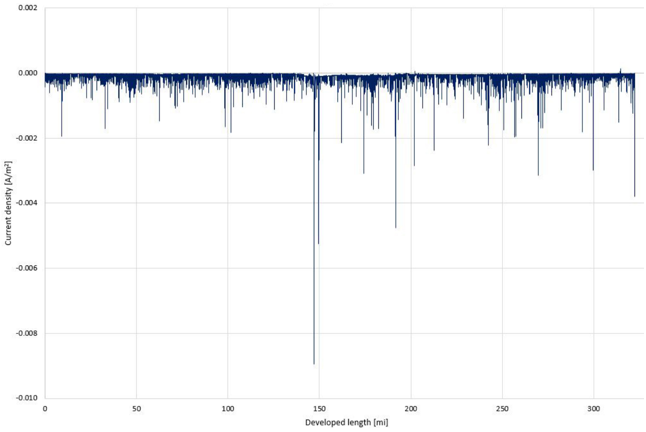

Figure 4. Simulated CP current density along the FBE coated pipeline.

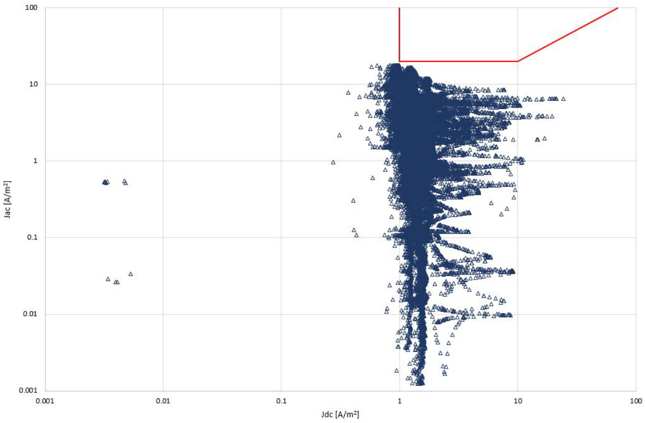

Figure 5. AC corrosion likelihood assessment based on simulated AC and DC current density on FBE coating defects.

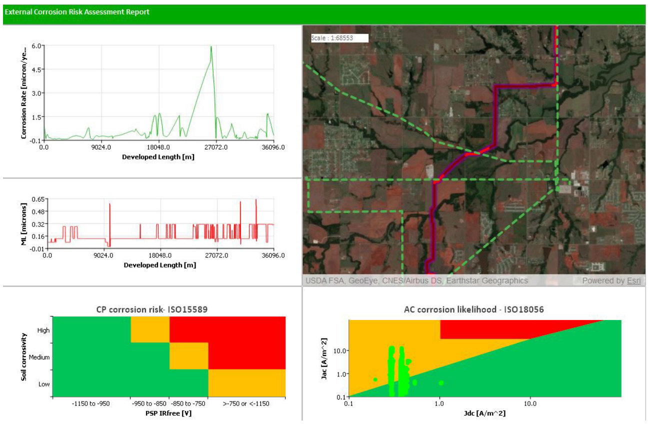

Figure 6. PIM dashboard for integrity risk assessment based on simulated corrosion rates.

voltage readings and the AC current drained by the mitigation systems (9 in total). The AC voltage was below safety limits of 15V. The simulated AC current density peaks to 18 A/m^2 at some locations and the simulated DC current density is above 1 A/m^2 in the majority of the pipeline sections. Combining both parameters allows assessment of AC corrosion likelihood according to ISO18086 and NACE SP21424.

Models to monitor

With a calibrated model in place, a profound integrity assessment is possible. First of all, the models are used to monitor the corrosion health status of the pipeline by feeding the mechanistic models with periodic field data. The data may originate from annual surveys or from remote monitoring devices installed in rectifiers or test points. Updating the model on a regular basis delivers a new status of the instantaneous corrosion rate on the pipeline. Integrating the corrosion rate over the time span between data refreshment results in certain metal loss. The metal loss is then accumulated and the total metal loss or corrosion growth rate over the entire pipeline length is obtained.

Secondly, one of the largest threats on pipelines is AC and DC interference. This may be very dynamic in nature and thus require accurate monitoring. The AC and DC current density at coating defects is essential in the proper assessment of pipeline interference risks. The NACE SP21424 or ISO18086 provides guidelines for assessing AC corrosion likelihood on pipelines based on a DC current density of 1 A/m^2 and AC current density of 20 - 30 A/m^2 threshold values. Similarly, the ISO 50162 for DC dynamic stray current refers to IR-free potentials and current density. Both AC and DC current density is simulated for the entire pipeline and can further be verified with coupon/probe readings at strategic locations which are selected in a mechanistic model.

Conclusions

Corrosion integrity assessment of pipelines requires knowledge of corrosion rates, as conventional ECDA programmes only provide indirect and ambiguous results on risk assessment. Reliable corrosion rates are difficult to obtain from indirect inspections and can impact the number of costly direct examinations that actually need to be executed.

To comprehensively monitor pipelines for active corrosion and continual health status, current densities (both CP, DC and AC stray current) must be simulated with mechanistic models. Based on the current densities and soil properties, the corrosion rate at coating defects is computed and represented in risk diagrams according to international standards. When connected to RMU and field survey databases, timely response on the dynamic fluctuations in the CP operational conditions and increased interference threats is then achieved. The resultant metal loss monitoring can then be applied for decisive risk integrity assessments.

Effectiveness and efficiency of the corrosion prevention programme will significantly increase by adopting a performance/risk-based management approach. Rather than applying general criteria, the method enables the pipeline operator to establish unique and time dependent parameters/tolerances for each particular line segment situated within specifically defined boundaries. Such considerations are in direct alignment with Section 6.2 of NACE SP0169-2013, which highlights the significance of physical and electrical characteristics of the pipe and its residence environment. Additionally, extracting maximum value from all available data sources can be achieved through the comprehensive integration and analysis that can be delivered by mechanistic modelling where environmental factors, ILI metal loss reports, and cathodic protection information are all accounted for.