CORROSION AND COATING DEFECTS ON BURIED PIPELINES UNDER CP: EXCAVATIONS DATA COLLECTION AND ANALYSIS.

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Onshore gas transmission pipelines are conjointly protected against external corrosion by an organic coating and by cathodic protection (CP). Owing to particular defects or coating aging in the long term in ground, the protective efficiency of this dual system may be impaired. Consequently, external corrosions may develop and, eventually, threaten the integrity of the line if not detected and mitigated in time. To ensure continued protection of its lines against external corrosion, Gaz de France carries out, routinely, several maintenance and monitoring activities on the CP system. In addition, above ground surveys allow a better assessment of possible coating faults. However, it is necessary to continuously improve the reliability of the corrosion prediction to optimize the maintenance of pipelines.

When indications and measurements from any mean of inspection (in-line inspection or aboveground surveys) lead to suspect the presence of any significant metal defect, an excavation of the concerned pipe section is performed. At each excavation location, many parameters are collected to document the existing conditions of coating and steel. If sufficiently extended and reliable, this information may help to understand the root causes for development of corrosions. Eventually, thorough analysis of field data resulting either from inspection or from maintenance operations could lead to corrosion prediction. Since the volume of these data is large, reliability and consistency of information is absolutely required. Gaz de France has implemented a systematic data collection procedure on excavation sites, together with data analysis through a range of treatment methods. Data on more than 1400 excavations, pertaining to a set of different selected pipelines, have been collected in a single database. The later contains data such as pipelines characteristics, local cathodic protection parameters at the time of excavation, coating defect description if any, characterization of the surrounding ground and environment at the time of excavation, as well as a documentation of the metal damage, if any.

Data analysis as well as statistics can then be applied to process these data. For instance, standard data treatment methods allow the compilation, on sub sets of pipelines with identical coating type, of the distribution of the number of coating defects and/or corrosions with respect to the pipeline age. It can also be attempted to relate those distributions with ground type or other relevant parameters, and to compare these
distributions with regards to the coating type. Eventually, the studies may, for example, reveal any correlation between the type/size of coating defects (disbondment, lack of coating...), and the presence (or lack) of a corrosion fault, and help to analyze the significance of such correlation.

Later on, more sophisticated statistics, together with input from fundamental knowledge and expert judgment, may help to pin out the risk factors leading to corrosion.

This paper will focus on the benefits of properly capitalizing field data collection and analyzing field data to better understand root causes of degradation of the (coating + CP) system protective efficiency. Ultimately, it is intended to show how such activities may support integrity and safety management of the whole transmission pipeline network.

**Keywords**: Coating faults, corrosion faults; underground Pipelines; Excavations; Data analysis

**Introduction**

Gaz de France operates 31,000 km of onshore gas transmission pipelines, of an average age of 25 years old, with the oldest lines in service since 40 to 50 years. It is known that, on aging lines, external corrosion may become a significant risk to pipeline integrity, in the long term [1, 2, 3, 4]. The crucial importance of properly maintaining the CP functionality during the whole pipeline lifetime, and particularly its adequacy with coating features and their evolution with aging is also now well recognized [5, 6, 7]. Since decades, Gaz de France carries out routinely monitoring and maintenance activities of the CP system, such as: survey of the rectifiers parameters, survey of electrical parameters of drain bonds between pipe and third party electrical equipments, survey of pipe to soil potential at test points [8] etc... This practise has been proved to ensure adequate external corrosion protection of the transmission pipelines network since its very first years of construction.

However, it is known that coating aging may impair CP efficiency, particularly in the presence of a coating disbondment inducing a shielding effect of the CP (current does not access to steel surface exposed to the soil corrosives [9, 10]). Moreover, “AC corrosion” risk due to parallels high voltage electrical transmission lines may be detrimental to pipelines integrity [11]. In order to maintain a high level of reliability of the transmission network, as well as extend the life expectancy of the lines and potentially reduce their OPEX, it is of a prominent value to precisely know the conditions of occurrence (i.e. the risk factors) of any external corrosion phenomenon - which may be a risk to the pipeline’s integrity. Corrosion appears when the dual protection is failing, i.e. there must be simultaneously a coating defect and a locally ineffective cathodic protection. The principal risk factors of underground pipelines with regard to external corrosion phenomena are roughly identified from numerous laboratory studies. However, the precise influences of specific field parameters on corrosion initiation and development remain unclear.

Gaz de France performs, for years, specific inspection activities aimed at locating coating defects and characterizing steel status at those locations. On the basis of prior knowledge and field feedback analysis, pipelines sections are ranked with respect
to their estimated external corrosion relative risk. Inspection activities (in-line inspection and/or above ground surveys), are then implemented, taking account of the results of this ranking process. Where coating faults have been suspected from measurements and indications, excavations are performed on the threatening suspected defects.

A database has been created to capitalize on all the data collected during excavations of selected locations on gas transmission pipeline sections.

The main objective of implementing this database is to get an overview of the status of metal at selected locations on Gaz de France transmission network. Further analysis of the influences of various parameters may help re-orientating the integrity management plans. Maintenance and inspection activities may consequently be redirected towards the pipeline under the highest corrosion risk.

This paper will first focus on the data collection methodology applied at each excavation, on the main properties of the database. Then it will illustrate the advantages of field feedback capitalization, with the support of some statistical data analysis.

Methodology

At each excavation site, coating defects, if any, are located. Then, the operators fill a data sheet concerning the pipe general data, identification of each coating defect, its description, the immediate environment, the local electrical measurements, the features observed at steel surface under the coating defect and, if present, the associated metal damage.

This form (one per coating defect identified at each excavation site) is reported in an Excel© sheet. This sheet has been especially conceived for guiding the operator who fills it (pre-set format of variables, fixed number of practical details for observations and measurements). It controls data consistency during acquisition and thus, ensures an homogenous and reliable data collection process.

The compatibility between of the data sheet and the database allows an automatic transfer of the information from one to the other.

General data

Those data may be collected before the excavation as they refer to some extent to the history and the intrinsic properties of the line.

<table>
<thead>
<tr>
<th>Region</th>
<th>Pipeline</th>
<th>General data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operate Zone</td>
<td>Coating</td>
<td>Diameter (mm)</td>
</tr>
<tr>
<td>Commision Year</td>
<td>Contractor</td>
<td>Insulation value</td>
</tr>
<tr>
<td>Impacting Area</td>
<td>Pipeline diameter</td>
<td>Data type</td>
</tr>
</tbody>
</table>

The general data of the pipe include: region and operational area names, the pipe section identification; its diameter and total length, the pipe’s main coating, its commission date, contractor’s name, the coating’s initial mean electrical resistance (measured on the line).

As a principle, this “General data” section gathers all the relevant information concerning previous inspections of the pipe: the cumulated length of inspected sections,
the inspection technique used, the number of coating or metal defects indications (either by in-line inspection or/and above ground surveys).

**Defect identification**

<table>
<thead>
<tr>
<th>Excavation number/ defect id</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilometric point</td>
<td>(m)</td>
</tr>
<tr>
<td>Test point location</td>
<td>(m)</td>
</tr>
<tr>
<td>GPS coordinates</td>
<td>Nord (m)</td>
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<tr>
<td></td>
<td>Est</td>
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<tr>
<td></td>
<td>Altitude</td>
</tr>
<tr>
<td>Place</td>
<td></td>
</tr>
<tr>
<td>Date of assessment</td>
<td>jj/mm/aaaa</td>
</tr>
</tbody>
</table>

When a metal damage is encountered, a specific sheet is filled by a specialized repair team. This sheet is also collected. The location of the nearest test point location is recorded as it allows comparison with historical data of cathodic protection. For instance, GPS coordinates allow the location of the pipeline on a geological map.

**Environment**

<table>
<thead>
<tr>
<th>Area type</th>
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<tbody>
<tr>
<td>Soil type</td>
<td></td>
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<tr>
<td>Specific point(s)</td>
<td></td>
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<tr>
<td>Topography</td>
<td></td>
</tr>
<tr>
<td>Depth of burial</td>
<td>(m)</td>
</tr>
<tr>
<td>Soil resistivity / method</td>
<td></td>
</tr>
</tbody>
</table>

As a general rule, the immediate environment of the coating defect is described as follows:

The type of area: either cultivation, industrial, urban, forestry or marsh area.

Any specific feature related to ground constitution in the vicinity of the coating defect is identified, i.e.: road, river or railway crossing, dump in the vicinity,.... Specific features related to the pipe construction or third party structures are recorded: casings, supports, parallelism with high-voltage cable (from 1000V), power line support, railway proximity…

For the sake of water draining ability of the soil, principal soil constituents have to be determined. This can be done by classifying soil texture: clay, sand, silt or mixed soil. Rock, stones, limestone or humus must be identified too, if present.

The topography of the surrounding ground is important to assess the possible water movements around the pipe (stagnation or flow, depending on the pipe section location and orientation with regard to topographical features - top or the bottom of a slope, parallel or perpendicular to the slope).

The resistivity of the soil in the excavation location near to the pipe is systematically measured either with a soil box or by the Werner’s four pins method.

4/13
Then, operators have to describe the coating defect features. If it is located on a particular area such as a stitching, a tap, a potential test point, a weld or on the body of the pipe, it is documented.

The actual type of coating is identified as it may differ from the current line’s coating (for instance in case a coating repair in the area) : coal tar or bitumen enamel (C), polyethylene (PE), field applied cold tape. Any particular feature of the pipe burying with respect to the prevention of coating damages such as selected backfilling with sand, use of rock-shields, padding by backfill crushing are reported.

As far as possible, the origin of the coating defect is evaluated : external mechanical interference (such as gouge or indentation), loss of adhesion, porosity, poor application, contact with a foreign material or improper repairs. Eventually, the size of the defect and the area of metal exposed to the environment are measured and recorded. In the presence of a disbondment of the coating, its size is evaluated. If water is present within the gap, pH is measured.

Metal damage assessment

If one or several metal damages coexist with the coating defect, a specific sheet of characterisation is filled. Among others, the depth of the damage, the surface area, and the type of damage (corrosion, external mechanical interference such as gouge or dent,...) are reported for further integrity and corrosion assessment.

A picture is taken before any brushing of the metal to assess the damaged area. In the presence of a deposit (whether it is corrosion products or calcareous deposits for instance), its colour, volume and adherence to the surface are evaluated and collected.

With respect to the further integrity assessment of the pipeline, assessment of the significance of corrosion defects is a crucial task. As a matter of fact, it is a very tricky because one has to infer, from the available features, when corrosion process initiated, whether it is still active. If so, the corrosion scenario needs to be identified and the most likely corrosion kinetic is to be evaluated.
At this time, Gaz de France is working on the characterization of the corrosion products to determine if an encountered corrosion is active or not. The sampling and analysis protocols for these products are still under investigation and out of the scope of the present paper.

**Electrical measurements**

Assessment of the local performance of the CP system is essential for the corrosion risk evaluation. To this end, a set of potentials and current measurement are performed by use of a steel coupon temporary connected to the pipe. The potential are always versus the Cu/CuSO₄ reference electrode.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe ON direct potential</td>
<td>(mV)</td>
</tr>
<tr>
<td>Pipe ON alternative potential</td>
<td>(V)</td>
</tr>
<tr>
<td>Frequency</td>
<td>(Hz)</td>
</tr>
<tr>
<td>Pipe OFF direct potential</td>
<td>(mV)</td>
</tr>
<tr>
<td>Instant coupon ON direct potential after linking to pipe</td>
<td>(mV)</td>
</tr>
<tr>
<td>Coupon ON direct potential 10 min after linking to pipe</td>
<td>(mV)</td>
</tr>
<tr>
<td>Coupon OFF direct potential</td>
<td>(mV)</td>
</tr>
<tr>
<td>Coupon surface area</td>
<td>(cm²)</td>
</tr>
<tr>
<td>Coupon DC current</td>
<td>(mA)</td>
</tr>
<tr>
<td>Coupon AC current</td>
<td>(mA)</td>
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</tbody>
</table>

Fundamental frequency of the alternative component of pipe ON potential is useful in order to distinguish between the presence of AC currents (e.g. : AC inductive current from electrical power lines) and the AC component of the cathodic protection rectified current (100 Hz). 100 cm² bare metal coupons buried in the ground may be used.

**Database content and features**

A computer program capitalizes the set of data collected on the excavation sheets. At this time, it contains more than 1400 excavations analysed in the past few years.

This application edits statistical reproduction of these data, updated at each new data entry. It is possible to access to a permanent statistical state of the transmission network.

Below follows some statistical items automatically generated by the application, for the whole set of the data :

**Inspection assessment**
- length of the inspected sections with a distinction per coating type,
- defect indications population,
- number of defect indications effectively excavated,
- number of excavations per inspected kilometre and possibly per type of coating.

**Coating defects statistics (on the basis of excavation data)**
- defects cause,
- defects location,
- defects clock position,
- defects associated with presence of a particular feature with respect to coating damage prevention, such as backfilling with sand, rock-shield, padding,
- distribution of defects compared to sections diameter,
- defects associated with a specific point,
- number of defects by excavation,
- distribution of defects versus area or soil type.

**Damaged metal statistics (on the basis of excavation data)**
- percentage of excavated coating defects with coexistence of metal damage,
- distribution of excavated metal damages with respect to sections diameter,
- distribution of each kind of metal damage, in the total set of excavated metal damages.

**Corrosion statistics (on the basis of excavation data)**
- number of external corrosion defects,
- pipelines affected by external corrosion,
- number of external corrosion defects compared to the number of coating defect indications.

These basic statistics can be completed by any request connecting the different available parameters.

Using such a field return collection framework pins out the most common and characteristic defects encountered on the transmission network. Using complex analysis methods such as multivariate analysis can highlight relevant factors having an impact on onshore corrosion risk.

**A few example of the use of statistical analysis**

**Warning**

One must be careful about the interpretation of the developed statistics performed on this database.

This base is for the moment restricted to a limited number of lines. The population should not be considered as representative of the network. Indeed, it gathers data on only defective sections of pipelines which were specifically chosen as such, selected on the basis of prior ranking activities. The first lines or sections to be inspected and documented were obviously the most likely to undergo a corrosion risk. In addition, the methodology used for excavation decision leads to a selection of the zones with the highest risk of corrosion. Consequently, corrosion defects frequency of occurrence in this database may be overestimated and may not reflect frequency that may be encountered on the whole network. Therefore, the real state of the network cannot be thoroughly inferred from these data.
Examples of statistics and analysis of database

![Diagram showing defects per inspected km]

**Figure 1. Relative levels of number of coating defects excavated per inspected km as function of the commission year.**

There is a peak in the relative level of number of coating defects excavated for the commissioning years around 1980-1985 (figure 1). In addition, on the lines in the same range of age, there is a tendency to encounter more corrosions among the coating defects revealed by excavations. At the beginning of the 80’s, Gaz de France (as most of the European operators) switched from coal tar or bituminous enamels to extruded PE coating systems. Although the usual ON/OFF potentials measures performed at this time confirmed that they were within the standards, there was obviously a lack of corrosion protection of some PE coated sections. This was quickly noticed by surface electrical measures. The analysis revealed that it was due the cohabitation of coatings on the network with different electrical behaviours, coal tar and bituminous coatings are indeed far less electrically resistant than PE ones. The same observations were made on other European networks. Mitigation measures were immediately implemented. They have proved since then to be successful as shown by the decrease of the proportion of corrosions found per inspected km, for the lines laid after the 80's. Moreover, the data illustrate the real effort of Gaz de France to inspect those lines.
Figure 2 shows the distribution, among the coating defects excavated, of the location of the coating defects around the pipe section. A third of the defects are located around the 6 O’clock position which may reflect that the lines were not properly laid in the ditch. There are also many defects located on the sides of the pipe, probably due to the installation and a lack of careful handling procedure. Defects at twelve O’clock seem to be scarcer, meaning that the backfill material is rather well controlled. 360° defects correspond, for most of them, either a missing field joint coating or disbonded field joint coatings. It is to be noticed that, insofar as Gaz de France has indeed very few lines coated with tapes, very few cases concerning such lines have been included in this analysis.

Figure 3: excavated coating defects, relative corrosion damages frequency revealed by excavations (by inspected km), and % corroded defects per excavation as a function of the coating type (distinction between C and PE).
Figure 3 depicts results of the analysis of the distribution, as a function of coating type, among the excavated coating defects, as well as the proportion of corrosion damages among the excavated coating defects.

![Figure 3.](image)

**Figure 4. Size of the coating defect per coating (Tapes (BF), enamels (C), PE 2 or 3 layers (PE2, PE3)).**

Figure 4 depicts the same kind of analysis for the surface area of directly exposed metal on the excavated coating defects. Three classes have been considered for this parameter named “coating defect size”: “small” corresponds to a surface lower than 700 mm², “medium” between 700 mm² and 30,000 mm² and “large” upper.

The figures are quite different from PE to coal tar or bituminous enamels. The collected data reveal, on the set of pipelines included in the analysis:

1. a higher relative number of detected coating defects on enamels compared to PE,
2. a much higher propensity of the excavated defects on PE coated lines to show corrosion damage compared to those for excavated defects on coal tar or bituminous enamels coated lines. Obviously it can not be inferred from this fact, that as a general rule, coating defects on PE coated lines are more susceptible to undergo corrosion than coating defects on coal tar or bituminous coated lines. Indeed, it is quite well accepted that above ground coating surveys are much more efficient with PE than with other coatings. Possibly, these results may simply display the well known link between the size of the coating defects (size of the exposed metal) and the propensity of the exposed metal to undergo external corrosion:

   First, the larger the exposed metal area, the higher is the current demand to the CP system,
   Second, the smaller the exposed metal area, the higher the likeliness of filling the coating defect mouth with corrosion products, enabling mitigation of the corrosion. As mentioned above, small size and enclosed coating defects, which are most frequently occurring for PE coated lines, tend to develop, owing to shielding effect, light corrosion...
damages without any risk to pipeline integrity, as a general rule and excluding particular situations such as electrical interferences. However, the more a coating disbands, the higher the corrosion rates as depicted by the following figure.

Disbondment size has been collected into three discrete values:
“small” corresponds to a coating disbonded on less than 10 cm around the defect, “medium” to a disbondment extent between 10 and 30cm, “large” more than 30cm.

The apparent corrosion rate increases with the size of disbondment with a ratio of almost 2 between the corrosion rates encountered in the presence of large disbondings and corrosion rates encountered in the absence of disbonding (open defect). Figure 5 simply shows that cathodic protection is efficient in the presence of open defects, but may fail in the presence of an open defect with a large disbonding, especially when the coating disbondment configuration allows a water circulation underneath. This is most probably mainly due to the shielding effect, as it has been reported previously that Gaz de France coatings retain good insulating properties, even after decades of aging in operational condition [12]. Gaz de France is indeed presently studying corrosion underneath disbonded coating. Preliminary results [13] tend to reproduce the field experience.

One must be carefully about the corrosion rate and the depth of a corrosion defect. In this study the corrosion rates are assumed to be steady with time and to have started on the commission day: total depth divided by the age of the pipe. This evaluation can be misleading: these corrosions may have been mitigated for a long time by a finer tuning of the cathodic protection or developed only recently.
Conclusion

Due to the limited available resources, in time and cost, prioritizing pipeline maintenance actions on a gas transmission network, on basis of risk levels, is a necessity. Capitalizing on information collected from excavations may significantly help the prioritisation task. When capitalizing on all the information concerning a “defect” (being a coating and/or a metal defect), one can better understand the cause of this defect, which may help to assess in which terms such defect may raise any concern for pipeline integrity in the long term, and consequently adjust protocols of next inspection and/or rehabilitation of a pipe. Gaz de France has implemented a database for collection of data gathered from excavations.

Data acquisition problems, data consistency issues, have been noticed during database implementation, specifications have been improved. These collection of information during excavation should be reliable and their gathering process may still be improved. As a matter of fact, this database is still incremented and ameliorated.

As sometimes there are missing or false information, more sophisticated statistics will be applied to get relevant parameters leading to corrosion. Data mining (factor analysis by correspondence or segmentation for instance) could be useful to analyse this database. There are technical limitations to deal with large, incomplete and evolving data bases with standard statistical methods. The potential of artificial intelligence to process this kind of data base is presently studied.

This field return capitalization and analysis will be used to validate prediction or estimation of specific corrosion risk: e.g. compare projected risk areas in terms of soil hydromorphism, type of soil, proximity of stray currents with real defects.

The first results illustrating this paper, although not reliable yet, as they are only representative of the selected set of pipeline and not of the whole network, are encouraging.

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