A36

Pipeline Insulation Quality Estimation with Superficial Electromagnetic Methods

V.A. Shevnin* (Moscow State University), A.A. Mousatov (Mexican Petroleum Institute), E.K. Nakamura (Mexican Petroleum Institute) & O. Delgado-Rodriguez (Mexican Petroleum Institute)

SUMMARY

Estimation of insulation quality from the earth surface with the help of magnetic and electrical measurements is important task for pipeline industry. Pipelines are under operation in underground conditions during tens of years and periodical inspection should be performed. Some pipes can't be inspected from inside, only superficial inspection is possible. Pipeline inspection works with very long profiles and in the same time needs high resolution. In DC electrical methods only electrical signals are measured while in AC electromagnetic methods mainly magnetic field measurements are used. In Mexican Petroleum Institute new technology of pipeline characterization named Surface Electromagnetic (SEM) Technology for Pipeline Inspection was developed based on the approximation of a metallic pipeline by heterogeneous transmission line with variable distributed parameters. Developed field operations and interpretation procedure allow us quantitative determination of insulation resistance and uncoated area rate evaluated on both magnetic field and electrical field data. Magnetic and electrical observations have different measurement time (magnetic survey is about an order faster) and different spatial resolution to insulation damage. Their integration is quite reasonable and provides complete pipeline characterization because includes reconnaissance survey and detailed study of anomalous zones. The examples presented demonstrate the efficiency of the SEM technology.
Introduction

For pipeline characterization with superficial geophysical DC methods: CIPS (Leeds, 2005) и DCVG (Leeds, 1990) and AC methods (PCM User Guide, 2006) are used. Each method has its advantages and disadvantages. To make every method's application more effective its technology became more complicated and several different methods are used together, how it was recommended by NACE (NACE Standard RP0502-2002).

In CIPS and DCVG methods signals are different when cathodic protection system (CPS) is on and off. That is why all measurements in these methods are fulfilled with periodical switching CPS on and off. Such measuring technology made instruments more complicated. For both DC methods non-polarizing electrodes are needed. DC signal when current is on includes metal pipe polarization potential and some influence of leakage current generated by CPS and passing through insulation defects and soil. AC methods are used magnetic field measurements. Magnetic field depends on total current in pipeline at the studied frequency. Change of current or attenuation characterizes leakage current passing through insulation defects and the influence of metal resistivity and its magnetic properties.

In fig.1 there are several graphs of current, magnetic and electric field behavior: a) pipeline with insulation damage; b) insulation resistance for pipeline from a; c) total current in pipeline (the source is on the left); D) leakage current; E) electrical potential $U$ resulted from leakage current and $Ex$ and $Ey$ components on the earth surface; F) magnetic field above pipeline measured with the step 1, 5, 10, 20, 40 and 50 m.

Leakage current from insulation damage is the source of electric field anomaly. Anomaly width depends on damage width and pipeline depth. That is why optimal step between measurements is 1-2 m. Source of magnetic field anomaly is integral from total current in infinite limits or at least in $(\pm 10^5 h)$ limits, where $h$ is pipeline depth. That is why step between measurements can be between 1 and 50 m without lost of information from insulation damage. Measuring velocity along profile in the case of magnetic measurements is at least 10 times faster in comparison with electrical components measurements. But electrical measurements have higher resolution to small damages. That is why combination of two techniques - fast magnetic survey at regional level and detailed electrical measurements in anomalous zones can be more effective.
For quantitative estimation of insulation damages we need to know all factors influenced on magnetic and electrical anomalies. Theory for pipeline inspection in MPI was developed on the approximation of a metallic pipeline by a heterogeneous transmission line with variable distributed parameters: resistance R and inductance L along a tube and leakage conductance G and C (Fig.2) (Mousatov et al., 2001-2004). We found that together with magnetic field (or electrical field) we need to measure pipe potential resulted from the source of current (AC generator). Instrument and technology for potential measurements were developed. We also need to know pipe depth and soil resistivity, the first parameter can be found from magnetic measurements, soil resistivity is measured with standard resistivity survey with AMNB array or with EM instrument.

**SEM Technology, developed in the IMP (Instituto Mexicano del Petróleo)**

SEM technology can resolve such problems:

- Determination of pipeline position in plan and depth;
- Quantitative estimation of leakage resistance and pipeline insulation resistance;
- Pipeline separation into zones with different grade of insulation damage;
- Determination of electrical bridges between pipelines in operation and out of operation also connected to CPS;
- Determination of illegal connections to pipeline;
- Estimation of charge of pipeline or pipelines connected to CPS.

Insulation quality we determine with the help of two parameters: insulation resistance and holiday's rate (length of damages in some pipe interval in percent to the interval length).

Data processing includes several operations. Approximation of current graph by rectilinear segments and calculating leakage current per unit of length $I_L$. From leakage current ($I_L$) and potential ($P$) a leakage resistance ($T_L$) is calculated $T_L = P / I_L$ (1). Leakage resistance $T_L$ is a sum of insulation resistance $T_i$ and soil resistance $T_m$: $T_L = T_i + T_m$ (2).
By using measured soil resistivity $\rho$ we obtain soil resistance $T_m$ and insulation resistance $T_f$. Uncoated area rate ($s/S$) is calculated on formula (3)

$$s/S(\%) = \frac{T_m \cdot (T_f - T_f)}{T_f \cdot (T_f - T_m)} \cdot 100$$  \hspace{1cm} (3)

where $T_f$ is insulation resistance, $T_f$ is ideal insulation resistance (it depends on insulation type), $T_m$ is soil resistance.

Electrical field intensity produced by leakage current $I_L$ we measure with MN line oriented perpendicular to pipeline with one electrode above the pipe $\Delta U_y$. Measurements of $\Delta U_x$ component are also possible, but $\Delta U_x$ graphs are more complicated (Fig.1E, Fig.3). $\Delta U_y$ depends on leakage current, soil resistivity and pipe depth:

$$\Delta U_y = \frac{I_L \cdot \rho_m \left( \frac{1}{\sqrt{Z^2 + X^2}} - \frac{1}{\sqrt{Z^2 + X^2 + Y^2}} \right)}{4 \cdot \pi}$$ \hspace{1cm} (4)

where $Z$ is pipe depth, $X$ is the distance between leakage current point and measurement positions, $Y$ is the distance of the second electrode from the pipe traverse.

We suppose that each unit of length (1 m) can be considered having its own leakage current $I_L$ that can be determined as continuous $I_L$ distribution along pipeline, this is the model of continuously distributed point sources. When we know $I_L$ and potential distribution we can calculate leakage resistance, insulation resistance and uncoated area rate on electrical measurements like on magnetic measurements.
Comparison of pipeline insulation damage determined on magnetic and electrical field measurements.

Both measurements give similar results (Fig.5). Magnetic measurements are faster but due to integral character of magnetic field have less resolution. These are suitable for fast reconnaissance survey. All zones with low insulation resistance can be studied with electrical field measurements, slowly but with maximal resolution. Pipeline inspection works with very long profiles and in the same time needs high resolution. Integration of magnetic and electrical measurements helps to satisfy these contradictory demands.

Conclusions
Estimation of insulation quality from the earth surface with the help of magnetic and electrical measurements is important task for pipeline industry. There are several technologies (CIPS, DCVG, PCM, etc.) that fulfill inspection at qualitative level, these have no theory and don't measure all parameters needed for quantitative conclusions. SEM technology is based on the theory and allows developing instrumentation, field procedure, data processing and interpretation for all practical needs.

Electrical measurements give high resolution, but speed of measurements is low, magnetic measurements are ten times faster. Integration of magnetic and electrical measurements helps performing pipeline characterization faster and obtaining results in the same quantitative parameters.

References
CIPS - Close Interval Potential Survey: www.corrpro.com
C-Scan - Dynalog Electronics Ltd. United Kingdom: http://www.dynalog.co.uk
NACE Standard RP0502-2002, Item No. 21097. Standard Recommended Practice Pipeline External Corrosion Direct Assessment Methodology