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Utilizing Impressed Current Cathodic Protection as the Source for Electromagnetic Exploration

M. Becken* (University of Münster) & T. Lindau (University of Münster)

SUMMARY

Central Europe is criss-crossed by pipelines to transport water, gas and oil. Metal pipelines are routinely protected against electrochemical corrosion with a coating supplemented with an impressed current cathodic protection (ICCP) system. For pipeline integrity tests, the rectified injection current is temporarily switched on and off. The switching scheme effectively generates time-varying electrical currents and induces secondary electric and magnetic fields in the subsurface, which decay spatially and temporally as a function of subsurface electrical resistivity. Here, we describe our first attempts to measure and to analyze the induced electromagnetic fields generated by switched cathodic protection currents in order to determine the subsurface electrical resistivity structure in the upper (few) kilometers depth range. This approach is closely related to controlled source electromagnetics. It may provide a cheap complement to existing electromagnetic geophysical sounding techniques, which is applicable in noisy environments without facing the logistical challenge of the installation a strong current source in the field. The methodology can aid in geophysical subsurface reconnaissance addressed in the exploration and monitoring of resources, reservoirs and geological storages.

Introduction

An ICCP system consists of an electrical current source, which is connected to a pipeline segment and to an additional anode buried in the ground. Typical currents injected into and leaking from the pipeline into the surrounding soil range between some mAmps to tens of Amps, dependent on the type of coating and the insulation thus being achieved. Coating defects cause additional localized current leakage into the ground and are associated with a drop of the electrical potential at the surface above the pipeline. To separate the potential caused by ICCP from the background electrical potential, pipeline integrity surveillance measurements are carried out with the impressed current being switched on and off. A standard switching scheme with an on-time of twelve seconds and an off-time of three seconds (i.e. four cycles per minute) is applied throughout Germany. These technical parameters suggest that ICCP systems are suited for EM exploration, since the signal periods and the dipole moments are comparable to those employed in CSEM. The major difficulty in utilizing ICCP as the source for EM exploration is to describe the source parameters with sufficient detail. Whilst the geometry is well known, the distribution of currents along each pipeline segment depends on the galvanic coupling of the pipeline to the surrounding subsurface and is a priori unknown.

Pipeline current distribution at a test segment

A 30 km long pipeline segment near Herford, Germany, was selected as a test site for detailed studies. The current injected into the pipe originates in a 50Hz AC signal which is being rectified. If we assume that the geometrical distribution of the current is independent of frequency, we can separate the current function $I(\mathbf{r},\omega)$ into a position- and a frequency-dependent part, respectively, as

$$I(\mathbf{r},\omega) = I_r(\mathbf{r}) I_\omega(\omega)\,. \tag{1}$$

We determined $I_r(\mathbf{r})$ using a pipeline detection tool. This device utilizes small air coils to measure the 100 Hz magnetic field associated with the rectified current and employs Biot-Savart's law to estimate the depth, the current and the horizontal position. In theory, these parameters can be uniquely determined from two horizontal magnetic field measurements at two different heights and from the nulling of the vertical component to find the horizontal position. Current measurement along the test segment, depicted in Fig. 1b, suggest an exponential decay of the current towards both ends of the pipeline segment. This is indicative for a quasi-continuous current leakage. The total dipole moment of the considered segment amounts to 6000 Am.

Induced electromagnetic field

The measured position-dependent current distribution $I_r(\mathbf{r})$ allows us to model the electromagnetic response from the pipeline source. For this example, we approximated the pipeline with a total of 101 straight finite wire sources (cf. Streich and Becken, 2011). Each of the wires was assigned a constant

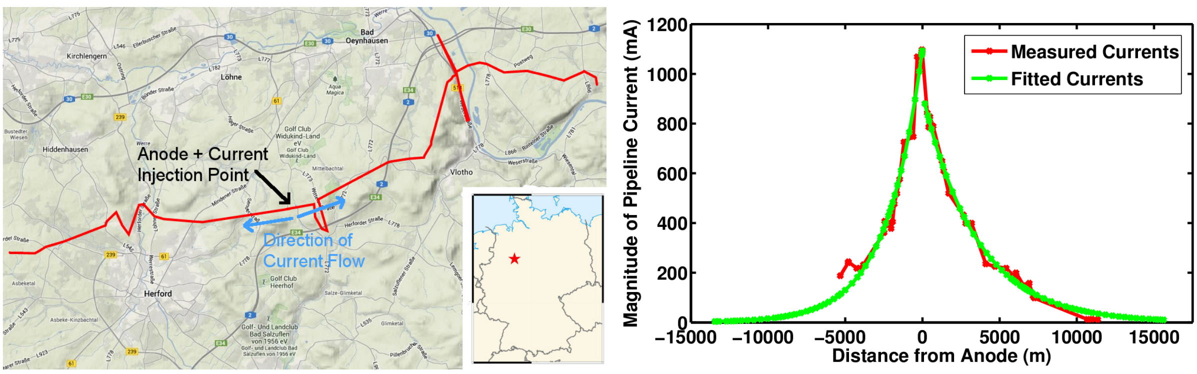

Figure 1 *a) 30 km long pipeline test segment (red line) near Herford, Germany. b) Measured decay of impressed current, fitted with an exponential function.*

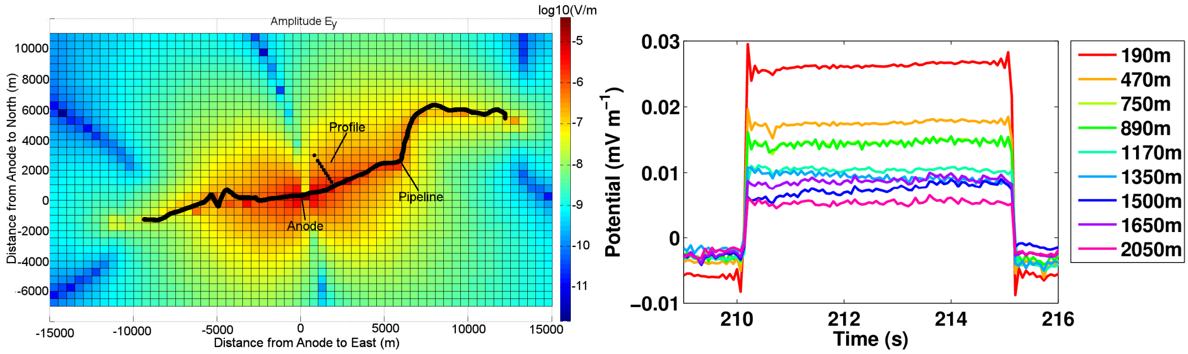

***Figure 2** a) E_y model response for a 7 ohm-m half-space. b) E_y recordings at various distances along a profile perpendicular to the pipeline.*

current, determined from the graph in Fig. 1. Figure 2a depicts the modeled amplitude of the east-directed E_y surface field in a conductive environment (7 ohm-m half-space) for the frequency of 1 Hz. Note that the field exhibits a quadrupolar characteristic, reflecting the current flow in opposed directions from the central injection point.

We carried out electromagnetic field recordings along a 2 km profile perpendicular to the pipeline (dots in Figure 2a). A total of 9 simultaneously recording stations were deployed for one week. In addition, a synchronous recording of the injection current was realized. For the duration of the measurements the pipeline current was switched on and off with a 30 sec cycle (25s on, 5s off). Furthermore, it was ensured that nearby pipelines were not switched during our survey. The data example in Figure 2b illustrates the data quality and the decay of the electric field with increasing distance (100 m to 2000 m) from the pipeline. Note that the measured potential drops are of the same order of magnitude as predicted by our modelling.

The fundamental period (30 s) and the visible harmonics for our recordings were found to span almost two frequency-decades. Simultaneous recordings of $I_\omega(\omega)$ at the injection point and a component $F(\omega)$ of the electromagnetic field at an observation can thus be combined into a statistical estimate of a transfer function $T(\omega)$, where

$$F(\omega) = T(\omega) I_\omega(\omega) \quad . \tag{2}$$

$T(\omega)$ carries the information about the electrical resistivity distribution and can be inverted with CSEM inversion codes.

Conclusions

Our preliminary study suggests that the electromagnetic signals generated by pipeline sources can be controlled und utilized for electromagnetic exploration. It must be noted though that this approach cannot replace CSEM studies with purposefully installed sources in order to achieve optimal survey geometry. In turn, it may provide a relatively cheap and safe complement to CSEM studies. Furthermore, pipeline sources may be suitable for time-lapse experiments for which the repetition error of the source installation may be a limiting factor.

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References

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