The determination and identification of stray current source influences on buried pipelines using time/frequency analysis

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Abstract

Purpose – The purpose of this paper is to detect the source of stray current interference on underground pipelines in urban areas using a joint time/frequency method of signal analysis.

Design/methodology/approach – Investigations are performed on an underground pipeline located in the vicinity of the two direct current tractions: a tramway line and a train line. The results of the analysis are presented in the form of spectrograms, which illustrate changes in the spectral power density of the potential of the rails and of the potential of the pipe in the joint domain time-frequency.

Findings – The comparison of the spectrograms can be used to evaluate if and which stray current source has influence on the investigated metal construction.

Originality/value – The combined analysis in the domain of time and frequency can be used as a supplementary one providing new information useful in the evaluation of stray current corrosion hazard. In the presence of several electric field sources in urban areas, this method reveals the complete time-frequency characteristic of each stray current source and its interference on the investigated construction.

Keywords Cathodic protection, Electric current, Corrosion, Electric field effects, Railway engineering, Transport engineering

Paper type Research paper

Introduction

One of the factors affecting the corrosion rate of an external pipeline surface in urban areas is the interference of stray currents. Electrified direct current (DC) rail systems (tramway, train and subway) are the main dynamic stray current sources. Some methods for assessment of a danger caused by stray currents are described in the Standard EN 50162:2006 "Protection against corrosion by stray current from DC systems" and are presented in various papers. Detection of stray current interference is usually carried out on the basis of the pipeline potential measurements versus a reference electrode, which is usually a copper/copper sulphate electrode. This potential fluctuates in the presence of dynamic stray current. The point of maximum exposure of a tram/train line may be pinpointed by correlating the pipe potential with the voltage between the pipeline and the tram/train rails (Peabody, 2001). Correlations are made at a series of locations through the exposure area. At each location, the slope of the *X-Y* correlation spectrum is calculated. The slope is a measure of exposure: the greater the slope, the greater the exposure.

The interpretation of the results is sometimes ambiguous (Zakowski and Darowicki, 2003), and quite a number of aspects of this problem still merit discussion (Freiman, 2003), especially when the correlation data potential-voltage will not fall along a straight line. Such a case may occur when several stray current sources affect the pipeline.

In this work, joint time-frequency analysis of measured signals, using the short time Fourier transformation, was used to obtain the characteristics of the stray current interferences on the underground pipeline in the vicinity of two electrified lines: a tramway and a train track. This method makes it possible to determine which of these stray current sources imposes the dangerous effect on the pipeline. It enabled choice of the proper form of electrochemical anticorrosion protection for the pipeline. The approach is useful for application in urban areas where there are many sources of stray current and when correlation analysis is insufficient to determine which source interacts with pipeline.

Method of analysis of measurement signals

The method, previously presented and applied to the detection and analysis of stray current field in the ground (Zakowski, 2007), employs the short-time Fourier transform (STFT) of the measured signal $u(\tau)$ described by the dependence (Quian and Chen, 1996):

$$\text{STFT}\{u(\tau)\} = \int u(\tau)\gamma(\tau - t)e^{-j2\pi f\tau}\,d\tau \qquad (1)$$

where:

τ = time;
γ = analyzing window function; and
t = time localization of the analyzing window.

The STFT transform differs from the classic Fourier transform (FT), i.e.:

$$\text{FT}\{u(t)\} = \int u(t)e^{-j2\pi ft}\,dt \qquad (2)$$

by application of an analyzing window function (Ramirez, 1985). This window, localized in a time instant t, cuts out a fragment of the analyzed signal. Outside the window, the signal is equal to zero. This fragment is subjected to the classic Fourier transformation and then $|\mathrm{STFT}\{U(t)\}|^2$ is calculated, i.e. spectral power density corresponding to the time instant t is determined. In the next step, the window is shifted to the following time localization and a new fragment of the analyzed signal is cut out. The spectral power density also is calculated for that fragment.

By repeating this process over the entire register, the evolution of the spectral power density versus time is obtained. One result of the analysis is a spectrogram, which reflects the time-frequency analysis of the registered signal (Carmona *et al.*, 1998). The spectrogram is the square of the modulus of the STFT transform and is defined in the domain of time and frequency. In this sense it is a measure of the energy of the signal with defined frequency for the defined moment of time (normalized value of z coordinate on the spectrogram for a joint time-frequency X-Y grid; Darowicki and Zakowski, 2004).

Experimental

The test experiment was performed with the setup presented in Figure 1. The aim was to detect several sources of electric field in the ground. The measurements were performed in the electric field generated simultaneously by two controlled sources of stray currents, i.e. alternating-current (AC) generators (Agilent Ltd, Santa Clara, CA, USA). Each generator was connected to one pair of auxiliary stainless steel electrodes placed in the soil 10 m apart. The soil resistivity was $60\,\Omega\,\mathrm{m}$. A voltage $U(t)$ was registered between two identical measurement electrodes $R1$ and $R2$ placed on the ground surface 1 m apart. Copper/saturated copper sulphate reference electrodes were used. The measurements were carried out with a 16-bit National Instruments PCI-6052E card. The sampling frequency was 10 Hz.

The arrangement of the main experimental setup is shown in Figure 2. The investigated object was a $\phi 300\,\mathrm{mm}$ underground steel gas pipeline that was more than 20 years old, coated with bituminous insulation, running parallel to the DC tram traction at a distance of 20 m. The measurements were performed at the place where both the pipeline and the tram traction lines crossed the DC train traction lines. At the

Figure 1 Arrangement of the test experiment setup
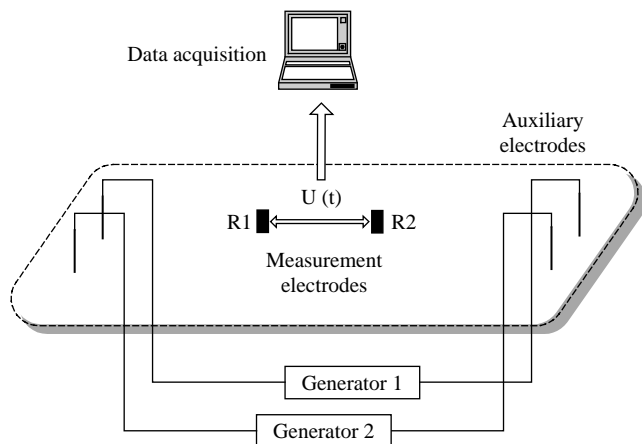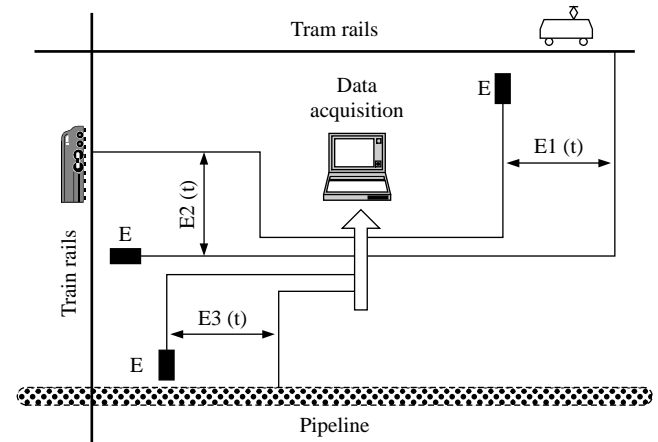

Figure 2 Arrangement of the main experiment setup

crossing, the train track ran above the tram track and the pipeline. Three potentials were registered simultaneously with respect to the reference electrodes E: potential $E1(t)$ of tram rails, potential $E2(t)$ of train rails and potential $E3(t)$ of pipeline. The potentials of the rails were measured using portable copper/saturated copper sulphate reference electrodes, placed on the ground surface 2 m from the rails. The pipeline potential was measured using so-called "permanent" copper/saturated copper sulphate electrode, buried and installed close to the pipe. Soil resistivity was equal to $110\,\Omega\,\mathrm{m}$. The measurements were carried out using 16-bit data loggers manufactured by IQ ComputerBoard. The sampling frequency was 8 Hz.

Results

An analysis of the registered signals was obtained using "LabView" joint time-frequency analysis software.

Figure 3 shows an example result of the test experiment. Initially two generators were operating: generator 1, sinusoidal field 1.5 Hz output amplitude 6 V; generator 2, sinusoidal field 1.0 Hz output amplitude 3 V. The former was turned off after 150 s, the latter after ca. 290 s.

The result of the experiment performed on the pipeline in the interference area of stray current generated by two DC powered rail transit systems is depicted in Figure 4. The spectrogram "(a)" shows the energy changes of the pipeline potential in the joint time and frequency domain. Spectrogram "(b)" – shows the energy changes of the tram rails potential, and Spectrogram "(c)" – shows the energy changes of the train rails potential. These potentials were registered simultaneously.

Discussion

The STFT spectrogram in Figure 3 indicates the presence of frequencies 1.0 and 1.5 Hz in the measured signal. It is also possible to compare the energies of both frequency components. It can be seen that the energy of the signal 1.5 Hz was higher than was the energy of the signal 1.0 Hz. Moreover, the periods of current generation by each source are evident in the spectrogram on the time axis.

The depicted result illustrates that the joint time-frequency analysis allows detection of the presence of several electric current sources (in this case AC generators). Thus, the STFT

Figure 3 Time register of voltage between measurement electrodes in the presence of two AC fields 1.5 Hz and 1.0 Hz generated in different instants of time, its classic Fourier transformation spectrum (FT) and its spectrogram (STFT)
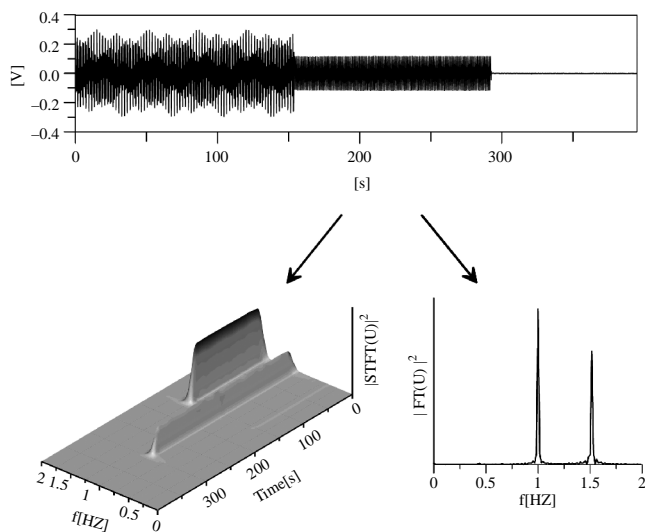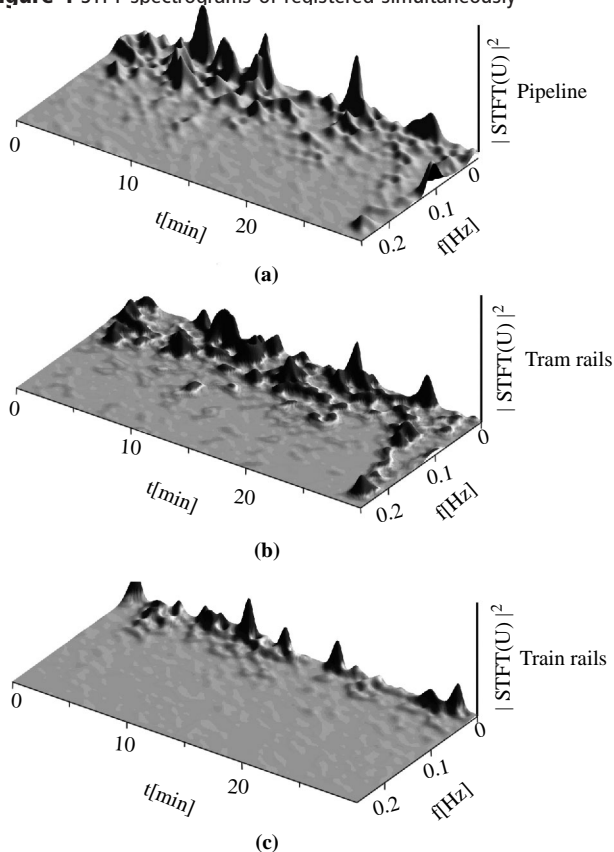

Figure 4 STFT spectrograms of registered simultaneously

(a)

(b)

(c)

Notes: (a) Pipeline potential; (b) tram rails potential; (c) train rails potential

analysis results in complete time and frequency characterization of the electric field generated by each source. This information is inaccessible using the classic Fourier transformation, which gives an averaged result for the entire period of measurement. Moreover, the frequency spectrum FT shows higher energy of the signal 1.0 Hz than of the signal 1.5 Hz (the inverse of reality), which results from longer duration time of the former.

The spectrograms "(a)" and "(b)" in Figure 4 are similar in form. It can be observed that at certain moments of the time, the signal energy for the same frequencies increases on both spectrograms. The changes in the spectral power density of the measured signals versus time are the same on the spectrograms "(a)" and "(b)". This characteristic shape of both spectrograms correlated closely with tram traffic. The same time and frequency location of spectral lines on the spectrograms "(a)" and "(b)" gave unequivocal proof that the stray current generated by passing trams affected the state of the investigated pipeline.

The shape of the spectrogram "(c)" correlated with the train traffic. It is indicated by an increase of the signal energy for very low frequencies at certain moments of time. The localizations of spectral lines on the spectrograms "(a)" and "(c)" were not the same. This means that stray current generated by the train line did not interact with the investigated pipeline.

The conclusion is important in respect of corrosion protection: in order to mitigate stray current effects, the presented results point to the necessity of installing a drainage bond only between the pipeline and the tram rails. A drainage bond to the train rail would be needless.

Conclusions

The presented results illustrate the exemplary use and the advantages of the applied analysis method. This method allows determination if and which stray current source(s) interact(s) with the investigated underground pipeline. The identical time and frequency localizations of spectral lines on the spectrograms corresponding to the pipeline and stray current source identify conclusively the interference source.

The presented method of analysis can be used as a complementary method to the traditionally applied measurement techniques of determining stray current interference, especially when measurements of pipeline potential data are ambiguous. The method further enables the correct choice of the form of electrochemical protection, which is important in urban areas where there are many sources of stray current and when traditional analysis is insufficient to determine which stray current source interacts with a subject pipeline.

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