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The role of stray currents in the evolution of damage in transport systems

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Abstract

The aim of the present work is the influence of stray currents on transport systems, especially rail and city systems. Therefore, a study was conducted that simulated flow of stray currents on elements of the transportation system. Steel DOMEX, which has enhanced resistance to corrosion, was used as research material. It is rarely understood that transport systems can have reciprocal negative effects on each other. For example, the urban and long-distance rail transport systems influence the transmission systems (gas pipelines, information systems). A side effect of the functioning of railways is the formation of stray currents, which cause electrochemical corrosion in all undergrounded metal components. It has been demonstrated that the impact of stray currents on the metal parts is of corrosive nature, and their effects can be presented graphically and numerically. It has also been proven that the anodic potential causes a greater loss than the cathodic potential. Furthermore, the exposure to the elements, both in the process of corrosion and erosion, accelerates the destruction of the material.

Introduction

The concept of stray currents is inevitably associated with the development of the catenary. With the launch of the first experimental electrically powered trams in Berlin, in 1881, and the subsequent electrification of all tram lines in the world, the phenomenon of stray currents was observed. In the first power networks, the propulsion of electric traction was supplied by DC (in Poland today traction network is powered by a DC voltage of 3000 V). The presence of electric currents was noticed to partially interfere with working circuits in the ground, causing significant corrosion of items such as metal pipe and cable sheathing. The local corrosion rate reached 5 mm per year (sometimes even more) leading to studies on the phenomenon of excessive corrosion, which resulted in significant losses and damages. As research work started the electrochemical nature of the problem had not been immediately identified.

Definition of stray currents

According to the encyclopedia, the phenomenon of stray currents is defined as “electricity flow via buildings, ground or equipment due to electrical supply system imbalances or wiring flaws. It refers to an existence of electrical potential that can be found between objects that should not be subjected to voltage”. More specifically the above phenomenon in the catenary, reverse current flowing in the circuit should theoretically flow to the traction substation by rail; however, due to the lack of perfect isolation of the transition section of the rail – ground resistance of the longitudinal rails – part of the current branches out, in accordance with the second law of Kirchhoff. Some of the currents returning to the substation through the ground, where the resistance is small, stray – hence the name of stray currents. These branches of the main current flow use all underground metal parts. During the flow of the current at the boundary between ground and metal components, there is a corrosion phenomenon of metal parts (Sokólski, 2007).

Due to the common power catenary circuit and the current used to generate traction in the rail system, the leakage phenomenon used to eddy currents is usually the only one considered, overlooking the influence of alternating currents. The source of these currents can be network traction powered by alternating current (used in some European countries), or the phenomenon of self-induction (the process may occur in long pipelines located near the high-voltage alternating current power line through the interaction of power cables, telecommunications, high-voltage lines and sometimes rail). Although the phenomenon of corrosion resulting from alternating currents is fairly well known, methods to protect metal components from this type of corrosion are still unknown. The reason for this is the lack of use of cathodic protection. Furthermore, the corrosion speed of the process, compared to the effect of DC on the metal parts, is fairly small (Stochaj, 2013).

Currently in Poland there are four standards for protection against stray currents, summarized in Table 1.

Table 1. List of standards in force in Poland (Sokólski, 2007)

PN-EN 50122-2:2002	Railway applications – stationary devices – Means of protection against the effects of stray currents caused by electric traction current.
PN-EN 50162:2006	Protection against corrosion due to stray current from direct current systems.
PN-W--89510:1997	Protection of metal objects against corrosion by stray current in shipyards and ports. General requirements and tests.
PKN–CEN/TS 15280	Assessment of the likelihood of corrosion of buried pipelines caused by alternating current. Application to cathodically protected pipelines.

The influence of stray currents on metal structures

As already mentioned, the main damage caused by stray currents is the electrochemical corrosion of metal parts, which occurs at the intersection between metal structures and electric traction lines. To prevent significant decrease in metal volume, the so-called cathodic method is usually adopted as a means of protection. Its basic functioning principle is the compensation of the effect of stray currents by applying an appropriate negative polarity metal structure, thus reducing or even completely eliminating, the discharge current. When the protection

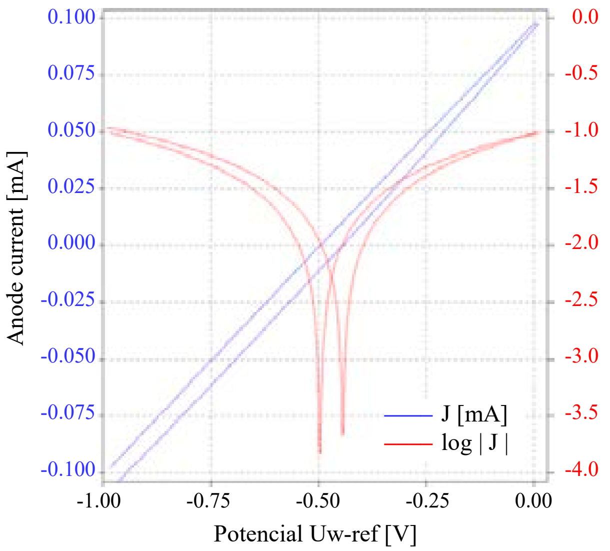


Figure 1. Voltammetric curves Domex steel in the soil solution

current from an external source is insufficient (e.g. poor insulation coating), the process of draining the stray current back to the electric traction network may be used in addition to cathodic protection (Baltskii & Chmiel, 2015).

In Figure 1, the blue curves show the current value, while red curves represent the logarithm of the absolute value of the current for increasing and decreasing potential.

On the basis of tests, it was determined that potential changes ranging from –0.5 V to –0.2 V are particularly important. Additional tests indicated a change in polarity of the potential from –0.3 V (for the HNO_3 solution) to –0.35 V (for NaCl). A significant shift of the peak potential during the return cycle in the NaCl solution, due to the formation of a layer of iron chlorides, was observed. A negative value of the anodic current in the circuit is a sign that conditions of cathodic polarization were created at the working electrode, with the consequent evolution of hydrogen (Norma PN, 2004).

It is noted that the current density in a 0.1 M soil solution and in a 0.1 N nitric acid solution reaches 50 mA. Therefore, it can be assumed that the scaling factor is approximately 500. It follows that 15 minutes of exposure of Domex steel in a 0.1 N nitric acid solution corresponds to about a week's exposure in a natural soil environment.

Corrosion and erosion research

The test was conducted based on the dynamic cyclical process potentiometer, which allows to determine the oxidation potentials (Figure 2).

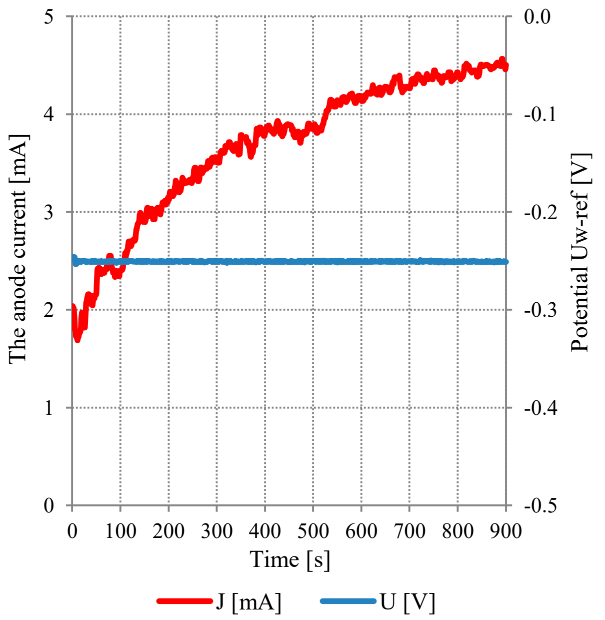


Figure 2. Changes in the conditions of corrosion current anode

The material used consists of Domex steel in the form of discs of 13 mm diameter and 4 mm thickness (cut elec).

The samples were prepared for the test according to the following procedure:

- Grinding flat surfaces on paper abrasive grit 500;
- Grinding test surface to grit 1000;
- Polishing test surface with a 3 micrometer diamond (Struers DP);
- Washing sample in methyl alcohol and drying in warm air;
- Weighing samples;
- Exposing samples to corrosion;
- Washing sample in methyl alcohol and drying in warm air;
- Weighing samples;
- Exposing erosion;
- Washing sample in methyl alcohol and drying in warm air;
- Weighing samples;
- Purifying the contact surface (grinding grit 1000).

Erosion Research was performed in the blasting shock chamber in accordance with ASTM G134 conditions:

- Pressure stream, PS – 12.5 MP;
- Counter-pressure in the chamber, PK – 0.25 MPa;
- Nozzle diameter, DD – 0.4 mm;
- Distance nozzle – sample, L – 10 mm;
- Temperature, TO – 22÷25°C (Norma ASTM, 2010).

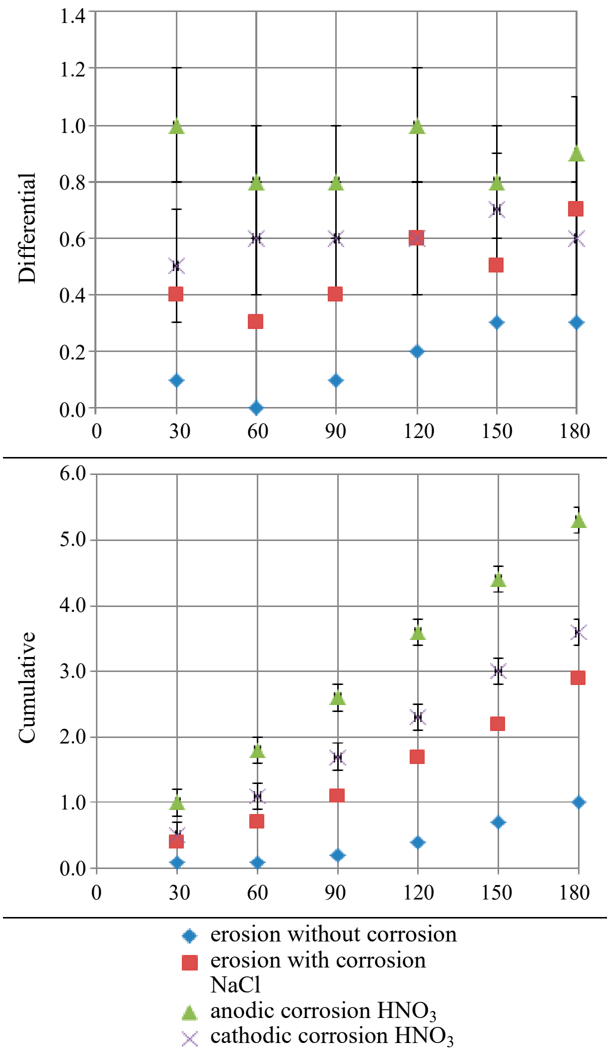
The aim of the study was to evaluate the erosion resistance of the material degraded in the process of corrosion by stray currents.

Determination of the evolution of erosion through gravimetric analysis

The aim of the study was to evaluate the erosion resistance of the material degraded by corrosion caused by stray currents. The simulation results are shown in Table 2. All results indicate material losses of DOMEX steel and are expressed in mg. A separate overview shows the cathodic and anodic conditions.

Table 2. Intensity of the erosion for individual processes

[mg] Comparing the intensity of erosion



Conclusions

The flow of currents in traction networks produces the undesirable phenomenon of stray currents. These currents have a negative impact on all metal parts in the soil as they cause electrochemical corrosion. The components most vulnerable to this phenomenon are those found in the passage of these currents to the substation, where the surface of the anode takes on a high potential.

A small change in capacity with respect to the passive state is sufficient to cause corrosion of significant intensity. For example, 10 mV of difference is able to cause a corrosion current density up to 10 mA/cm^2. The anode current density is the cause of the relatively large corrosion destruction.

Cathodic polarization is not sufficient to maintain the service life of the object due to the risk of hydrogen degradation of the metal. Beloglazov has shown that currents having a density greater than 3 mA/cm^2 promote intense absorption and diffusion of hydrogen into the metal material.

The simultaneous exposure of object to the phenomena of corrosion and erosion is particularly dangerous. The synergistic effects can be divided into the following classes:

- Erosion accelerates corrosion as a result of the removal of the passive layer. Under the conditions of the experiment, the accelerating agent can be quantified as 50;
- Reduction of the erosion resistance of the material as a result of electrochemical corrosion and hydrogen degradation by a factor of 3 to 5, compared to conditions in which corrosion does not occur;
- Creation of areas sensitive to corrosion as a result of the accumulation of stress and strain in the surface layer during the erosion process.

The presence of stray currents can disrupt conventional systems of anticorrosive protection and cause premature destruction of the object as a result of the simultaneous action of corrosion and mechanical degradation processes.

Steel with a micro supplement of boron showed relatively good resistance to degradation in hydrogen under the simulated cathodic polarization currents (Beloglazov, 2011).

Under the conditions of the corrosion experiment, the erosion process does not display the annular distribution of damage characteristic of pure erosion. On the contrary, the damage extends almost evenly over the entire surface, as is common with electrochemical phenomena. The process of erosion consists mainly in the removal of a layer degraded by corrosive phenomena. The effect of erosion is several times higher than in the case of corrosion-free conditions after only 90 minutes following the appearance of erosion in the central part of the sample. This can be explained as a consequence of hydrogen, which gradually deteriorates the material as a result of the electrochemical process and of cavitation (Chmiel & Łunarska, 2012). The presence of boron as micro-alloying additive can slow down the process.

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