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STRAY CURRENT MEASUREMENT AT THE TRAMWAY INFRASTRUCTURE IN OSTRAVA, CZECH REPUBLIC

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Abstract

In most transit systems, rails are used as return conductors for the current from the vehicle to the electrical substations. If the rails are not fully insulated from the ground, some of this current would leak and become stray current, causing stray current corrosion on the rails and metal objects (such as pipelines) in the immediate area. It is very difficult to measure stray current directly, but stray currents can be calculated by measuring other parameters. Stray currents were measured on a 1.3 km section of tramway infrastructure in Ostrava. The potential between rail and earth was measured on the basis of the standard EN 50122-2, where two reference electrodes were placed at an appropriate distance from the tram track at three measuring points in the ground - the first point was located at the beginning of the section, the second in the half of the section and the last at the end of the section. Rail currents were measured at two measurement points - the first point at the beginning of the section and the second point at the end of the section. Using the rail-to-earth potential and the equation from the standard EN 50122-2:2011, the rail-to-earth conductance per length was calculated. The conductance per length was also calculated using Ohm's law, where the current difference is a difference between two measurement points. Since the results obtained using the standard and Ohm's law did not agree, a detailed analysis of the tram section was performed and electrical drainage was found. The drainage represents an electrical connection of the protected metal structure in the area of the tram track by a cable with stray current source. Through the drainage, the stray currents are directly returned to the rail. In this measurement section, the drainage has influenced the current difference between the measurement points - without drainage, this difference would be much smaller.

Keywords: tram track, stray current, rail-to-earth potential, rail-to-earth conductance, rail current

1 Introduction

In most electrified rail traction systems, the catenary system is used as the conductor of current from the electrical substation to the vehicle and the rails are usually used as the conductor of current back to the substation, which means that the catenary system is positive with respect to the rails [1, 2]. Because it is very difficult to completely insulate the rail, and because of the finite longitudinal electrical resistance of the rails, some of the return current leaks from the rail and becomes stray current, which causes stray current corrosion on the rails [1, 3-5]. Current leaks because it finds another, less resistant path to return to the source, such as metal pipelines near the rail infrastructure. The current flows through

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the metal pipeline until it reaches the vicinity of the electrical substation. Then it leaves the pipeline and flows through the ground back to the rail (Figure 1). According to the authors [6], in a DC traction system, 5 % of the current flowing through the rail becomes stray current. Stray current corrosion occurs at any point on a metal object (rail, metal pipeline) where the current leaves the object and enters the electrolyte (soil, concrete, etc.) [7].

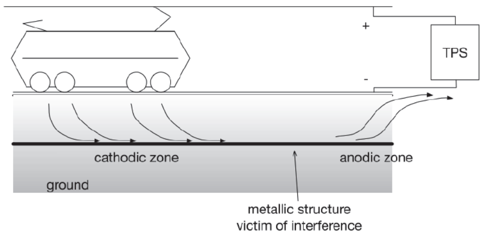

Figure 1 Stray current path in electrified tramway system [6]

The value of the stray current depends on the resistance between rail and ground. The higher the resistance between rail and earth, the less current flows from the rail. The resistance between rail and ground is determined by the insulation of the rail, the type of sleepers, the type of fastening system, and the quality of the ballast for ballasted tracks or the electrical resistance of the concrete layer for slab tracks. Methods for reducing stray current can be divided into two groups [8]:

- Increasing the resistance of the rail-to-ground leakage path,
- Decreasing the electrical resistance of the return path.

According to the standard [9], if following values of the conductance per length G'_{RE} and average rail to ground potential U_{RE} are not exceeded during the system lifetime, further investigations does not need to be performed:

- $G'_{RE} \leq 0.5$ S/km per track and $U'_{RE} \leq +5$ V for open formation
- $G'_{RE} \leq 2.5$ S/km per track and $U'_{RE} \leq +1$ V for closed formation.

2 Measurements at tram track infrastructure in Ostrava, Czech Republic

Tram track in Ostrava is ballasted tram track. Rails are fastened to the concrete sleepers on 1 m distance and laid on crush stone ballast. Since tram track in Ostrava is open formation, it was very easy to connect measurement equipment to the rails. In Ostrava tram track network, the positive pole is located on the rail, while the negative pole is at the catenary system (figure 2) [1].

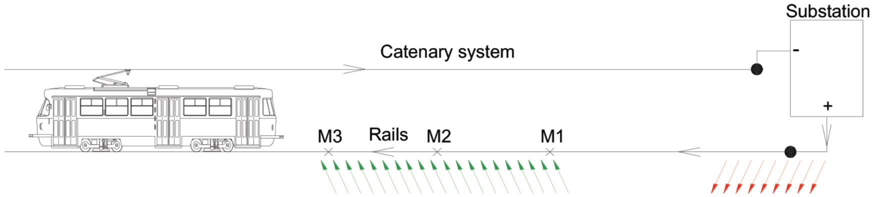

Figure 2 Current distribution at tram track infrastructure in Ostrava

It is very difficult to measure the stray current directly, but by measuring other parameters, the stray current on a section of rail infrastructure can be calculated. In the case of the tram infrastructure in Ostrava, measurements were made on a 1.3 km single-track section with relatively little traffic in the non-urban area at three measurement points - M1, M2 and M3 (Figure 3).

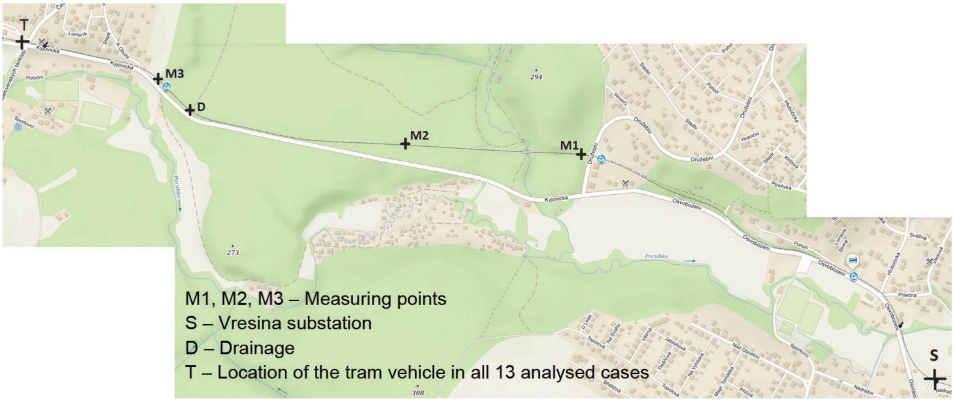

Figure 3 Map of the measuring segment with all necessary points

During the measurements, one electrical substation was shut down, so this section was supplied only by the Vresina substation. This substation is located 1.6 km east of measurement point 1 (marked with the letter S in Figure 3). All measurements were taken continuously and simultaneously for two and a half hours.

2.1 Rail-to-earth potential

At all three measurement points (M1, M2, and M3), the rail-to-earth potential was measured using two copper-copper sulphate reference electrodes as described in the standard EN 50122-2 (Figure 4) [9]. One electrode was placed in the ground at a distance of 7 m from the rail, the other at a distance of 40 m from the rail.

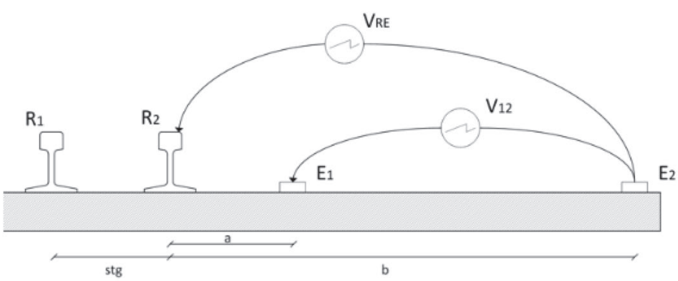

Figure 4 Measurement of the rail-to-earth potential [10]

At all three measurement points, the electrical resistance of the ground was also measured using the Wenner method. In the Wenner test, four electrodes are inserted into the ground at equal distances. The two outer electrodes inject current into the soil and the two inner electrodes measure the voltage. The ground resistance is calculated using Ohm's law [11].

2.2 Rail current

At the first and third measurement points (M1 and M3), the rail current was measured using the software on the computer. By measuring the rail current at these two points, it was possible to calculate the difference between measured values in MM1 and MM3. This difference should represent the stray current.

3 Results analysis

After the measurement was completed, the data were transferred to the computer and 10 different cases were selected for detailed analysis. In all cases, the tram vehicle passed through the measurement section or it approached the measurement section (Figure 3). Average values were calculated for each measured parameter in all 10 cases. The results are presented in Table 1, where:

- I_1[A] and I_3 [A] represent average current at the measuring point 1 and 3,
- U_{re1}, U_{re2}, U_{re3} [V] represent average value of the rail-to-earth potential measured at all measuring points,
- G_{re1}, G_{re1}, G_{re1} [S/km] represent calculated value of the rail-to-earth conductance based on the equation given in standard,
- G_{re} [S/km] represent average value of the rail to earth conductance for the whole measuring segment calculated using Ohm's law.

Table 1 Average values of the measuring results

Number	Measurements results Based on standard Based on Ohm's law					Rail-to-earth conductance [S/km]			
	I1 [A]	I3 [A]	Ure1 [V]	Ure2 [V]	Ure3 [V]	G're 1	G're 2	G're 3	G're
1	256	291	3.5	5.4	8.9	0.077	0.418	0.561	4.424
2	248	286	4.0	5.9	9.3	0.082	0.375	0.564	4.474
3	458	536	6.6	10.2	16.5	0.075	0.377	0.540	5.173
4	323	369	3.5	6.0	10.3	0.080	0.376	0.547	5.136
5	349	398	3.9	6.6	11.3	0.077	0.368	0.554	5.021
6	251	294	4.4	6.3	9.8	0.075	0.407	0.540	4.684
7	461	528	7.8	11.5	18.0	0.063	0.398	0.535	4.062
8	439	507	4.3	7.7	13.7	0.063	0.390	0.542	5.903
9	459	531	4.6	8.1	14.3	0.067	0.385	0.547	5.925
10	570	666	6.1	10.6	18.5	0.059	0.393	0.542	6.100

3.1 Rail to earth conductance using standard HRN EN 50122-2:2011

Rail-to-earth conductance was calculated using the equation 1:

$$G'_{RE}\left[S/km\right]=\frac{m_{sr}\cdot\pi\cdot 2000}{\rho_E\cdot\left[ln\cdot\left(b\cdot\left(b+s_{tg}\right)\right)-ln\cdot\left(a\cdot\left(a+s_{tg}\right)\right)\right]} \quad (1)$$

Where

m_{sr} – stray current transfer ration
ρ_E – electrical resistance of the soil
a – distance from the rail R2 and reference electrode E1
b – distance from the reference electrode E1 and E2
s_{tg} – tram track width.

The rail potential gradient DU_{1-2} was plotted as a function of the rail potential DU_{RE}. The slope of the linear regression of this function represents stray current transfer ratio (figure 5).

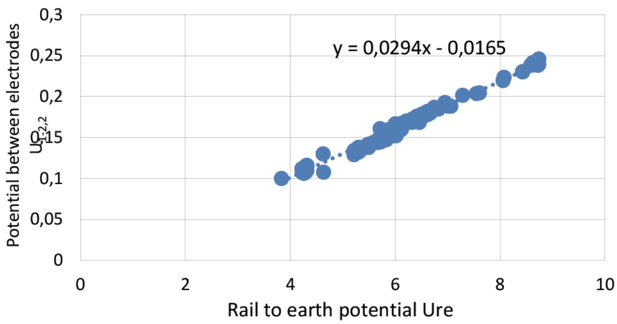

Figure 5 Example of the linear regression, stray current transfer ration for the measuring point 2, in case number 2; m_{sr} = 0.294

The HRN EN 50122-2:2011 standard [9] specifies maximum values for rail-to-earth conductance and rail-to-earth potential at which the structure is not at risk from stray currents. In the case of open construction of railway or tramway tracks, such as the construction of tramway tracks in Ostrava, the maximum rail-to- earth conductance is 0.5 S/km and the maximum rail-to- earth potential is +5 V [9]. As can be seen from Table 1, the maximum permissible values of the rail-to-earth conductance are not exceeded, but the potential is higher than the maximum permissible.

3.2 Rail to earth resistance using measured current values and Ohm's law

Based on the current difference between two measuring points and rail-to-earth potential between rail-to- earth, the conductance between rail and earth can be calculated using Ohm's law, equation (2):

$$G'_{RE}=\frac{\Delta I}{\Delta U\cdot l} \quad (2)$$

Where DU [V] represents average value of the rail-to-earth potential, DI [A] current difference between first and third measuring point and l [km] section length.

4 Discussion

The current value at measurement point 3 is higher than at measurement point 1, from which it can be concluded that current flows back into the rail at this measurement point. The results of the rail-to-earth potential also show that current flows back into the rail. At the part of the rail infrastructure where current flows back into the rail, the rail-to-earth potential should be negative. Since in these measurements the rails were considered negative and the electrodes were considered positive, the positive values of the rail potential mean that the rails are negative.
The values of rail-to- earth conductance calculated according to the equation given in the standard are different at each location. The average value at the first measurement point is 0.072 S/km, at the second measurement point 0.399 S/km and at the third measurement point 0.564 S/km. The values of the rail-to-earth resistance determined according to Ohm's law are significantly higher than the values determined according to the standard. The average value is 4.059 S/km. Due to the large difference between the rail-to-earth resistances, a detailed analysis of the tram track section was carried out and electrical drainage was found. The electrical drainage is used to protect metal structures located near the railway infrastructure from stray current. Drainage represents an electrical connection of the protected metal structure (e.g. pipeline) through a cable with stray current source [12]. Drainage bonding is based on a metallic connection between the metal structure and the rail. In this way, stray currents can flow directly back into the rail [2]. Since in this measurement segment a part of the stray current has flowed back into the rail through the electrical drainage (marked with the letter D in Figure 3), the current in measurement point 3 is significantly higher than without drainage.
As can be seen from Table 1, the values of the rail to earth conductance at measurement points 1 and 2 are less than the maximum permissible values, so that no further investigations or measures to reduce the stray current are necessary at this section.
Using Ohm's law, the stray current can be calculated, equation (3):

$$I_S = U_{RE} \cdot G_{RE} \tag{3}$$

Where:
U_{RE} [V] – rail potential, calculated using the equation given in standard EN 50122-2:2011
G_{RE} [S/m] – rail-to-earth conductance.

If the value of the stray current is known, the loss of material from the rail in a given period of time can be estimated using Faraday's law, equation (4) [13][14]:

$$m = k \cdot I_S \cdot t \tag{4}$$

Where:
m [kg/km] – weight of the material lost
k [kg/Ayear] – electrochemical equivalent (for steel is 9.1 kg/Ayear),
I_S [A/km] – average value of stray current
t [year] – time.

Stay current can be calculated using Ohm's law and the equations given in the HRN EN 50122-2-2011 standard. However, for this calculation, a continuous measurement of the potential between rail and earth must be carried out over a period of 24 hours.

5 Conclusions

In this paper, two stray current measurement methods are described. The current in the rail was measured at two measurement points. The difference between the measured currents at the two points should represent the values of stray currents. This measurement can be made in cases where tram traffic is relatively sparse and the measured section is supplied by only one electrical substation. In cases where the traffic load is higher, the measurement should be performed with a measurement vehicle while the tram traffic is stationary. In this way, the values of the current in the rails can be determined in situations where the vehicle accelerates, decelerates and travels at the same speed. After the measurement, electrical drainage was detected, so the current difference does not represent the exact value of the stray current in this section. The author's next step is to make the same measurement but with the disconected drainage. In this way, the influence of the drainage can be determined. Many stray current monitoring systems are based on continuous potential measurement between rail and earth. If the potential between rail and earth has changed, it means that the value of the electrical resistance between rail and earth has also changed, resulting in stray current leakage. Measuring the potential between rail and earth with a reference electrode is difficult to perform in urban areas because of the difficulty of placing the electrode due to asphalt surfaces.

The results of field measurements of stray currents are sensitive to many external influences, so it is very difficult to determine the actual values of stray currents. Stray currents must be considered in the design of new track systems. Good electrical insulation of the rails and rail fastening must be ensured so that the value of the resistance between rail and earth corresponds to the value specified in the standard.

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