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STRAY CURRENT CORROSION ACTIVITY ON RAIL TRANSIT SYSTEM IN URBAN AREAS

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Abstract

Corrosion reaction is a consequence of metal's natural reaction with the environment which can't be stopped by itself. Reactions like this are causing huge construction maintenance costs. The most common type of corrosion is electrochemical corrosion, which includes stray current corrosion – it is electrochemical corrosion that occurs mostly on railway structures in urban areas. DC (direct current) transit system operators are using rails as current returning path from the vehicle to the substation. When proper drainage of the track isn't assured, surrounding media in which rails are embedded becomes an electrolyte which leads to stray current leakage and development of corrosion. At the part where stray current is entering to the rail, rail in under cathodic protection. This is cathodic zone of rail. Corrosion occurs on parts where current is leaking from the rail, in anodic zone where deterioration of material under stray current corrosion effect can be notice. Different type of measures for reducing stray current leakage at the source are used among operators. At that way anodic reaction of metal (rails) with the electrolyte (media in which rails are embedded) can be stopped.

Keywords: electrochemical corrosion, stray current, anode, cathode, tram track

1 Introduction

Corrosion reaction of metal with liquid or moisture on metal's surface is electrochemical process. This means that metal's corrosion is a consequence of transmission charge between metal and electrolyte (ion conductor), [1]. Water, wet soils and aqueous solution of acid, alkali or salt are some types of electrolytes, [2]. At the metal/electrolyte interface oxygen – reduction reaction is happening. This reaction is defined by migration of electrons through the metal or between two metals that are immersed in electrolyte and mutually connected through metal conductor such as copper wire, [3, 4].

1.1 Corrosion cell

Reaction of oxidation can be defined as process of electron's releases and reaction of reduction represent process of binding electron with one substance or group of substance which is resulting with creating new substance or group of substance, [2, 4]. Final process of electrochemical corrosion can be described by the equation (1):

$$\mathrm{Red} \leftrightarrow \mathrm{Oks} + ze^{-} \quad (1)$$

In redox process oxidation and reduction reactions are happening on different places of metal's surface. Area on the metal where oxidation reaction is happening is called anodic zone and area on the metal where reduction reaction is happening is called cathodic zone, [3].

Anodic and cathodic reactions are caused by the electron transmission through metal (Figure 1). Speed of corrosion is defined by the speed of electron's transmission. When transmission is stopped, the electrochemical corrosion reaction is also stopped, [5]. This corrosion process is analogous to the process in galvanic couple, [6]. Two metals that are connected and immersed in some electrolyte are creating potential difference between them, which is resulting with the electron flow, [1]. Based on Faraday's low, if corrosion process is happening in corrosion cell, metal's losses on anode is proportional to the electric current in the cell, [2]. Mass-loss of iron due to corrosion current of 1 ampere in the period of one year is 9.1 kilogram, [7].

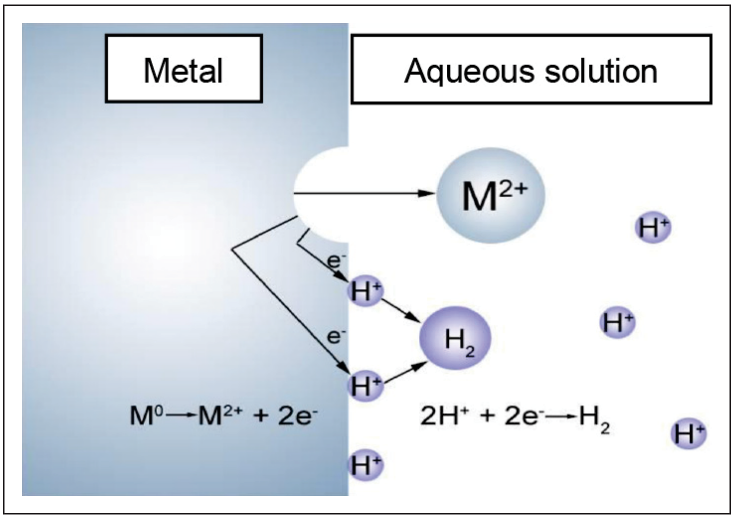

Figure 1 Schematic view of electrochemical corrosion, [6]

1.2 Electrolyte

Basic characteristic of electrolyte and electrolyte's solution is to conduct electrical current. Positively charge ions (cations) and negatively charge ions (anions) are carriers of electrical charge in the electrolyte, [1, 8]. In embedded railways the media (concrete slabs, asphalt) in which rails are places represent electrolyte, especially when, due to bad maintenance, adequate drainage isn't insure. In cases of bad drainage and presence of moisture and water retention in tracks electrochemical corrosion at the interface of metal (rail) and electrolyte is accelerated.

2 Stray current corrosion

2.1 Stray current

Stray current is part of the return current which follows paths other than the return circuit, [9]. Leakage of current from there intendent path is caused by placing insufficiently insulated metal conductor in electrolyte (ground, water), [1]. Considering the source of stray current, they can be static or dynamic. Static stray current is caused by cathodic protection on buried pipelines and source of dynamic stray current is mostly DC transit system, [9].
Due to the limitation of construction and maintenance costs, most DC transit system operators use rails as return path for the current from the vehicle to the substation, [10,11]. Since the rails have limited conductivity and rail insulation cannot be completely effective, part of the current that passes through the rails find new less resistance path and leaks from the rails through the electrolyte to the nearest buried metal object (mostly metal pipelines). Stray current continue its path through buried pipeline until it comes near the substation. At that place current leaves the pipeline and returns back to the substation (Figure 2), [1].

Stray current corrosion can produce damages on railway lines and on burred pipelines near the tram tracks. This type of corrosion is the result of external magnetic field activity on metal that is placed in electrolyte. In cases like this stray current corrosion cell is manifested due to external electrical field, [6]. Stray current corrosion cells is different from the regular corrosion cell described in section 1.1 this paper because it doesn't appear spontaneously, but under the external influence and in these cell electrodes aren't place near each other, [12].

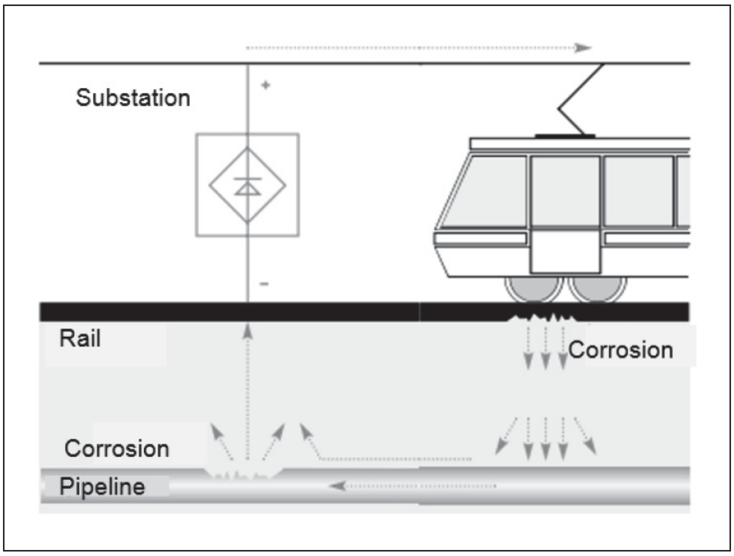

Figure 2 Mechanism of stray current corrosion, [13]

Cathodic zone is created at the place where stray current enters to the metal from electrolyte and the anodic zone represents place where stray current leaves the metal to enter the electrolyte, [7]. Distance between anodic and cathodic zone can be even few kilometre long, [6]. At the area of cathodic zone, construction is protected from corrosion by cathodic protection, but at the anodic zone the process of corrosion starts to happen. If this type of corrosion isn't noticed on time, material lost at the anodic zone start to happen, [9, 14]. The amount of corroded material on anodic zone due to stray current influence can be calculated using Faraday's low, [7].

2.2 Stray current detection at the source

Based on the norm EN 50162:2007 [15], amount of stray current and their source can be detected by measuring on buried metals object. In order to identify stray current polarity and magnitude potential gradient measurements at metallic can be carried out using two reference electrodes, [15]. One electrode have to be placed above the structure and the second one at a distance more than 10 m, [15]. By this measurement possible corrosion risk can be assess and static and dynamic stray current on that pipeline at the measuring period can be observed and recorded. Measured values can oscillate due to current source and different traffic load, which means that by measuring potential in the period of 24 hours source of stray current can be detected. If the biggest amount of stray current is noticed at peak hours (7 am to 9 am and 4 pm to 6 pm), when the traffic is increased, the main assumption is that the dc transit system is the source of stray current, [7, 15]. This measurement can give a good results only if the results are compared with an external event (like tramway passing) at observed moment, [16]. At the part of pipeline with the more negative potential then potential of the neighbouring soil, current is leaving from the rail and entering to the pipeline. This area represent cathodic zone at buried pipeline and anodic zone at the rail. In other case, if positive potential is noticed at the pipeline, current is leaving from the pipeline and enters at the rail (anodic zone on the pipeline, cathodic zone at the rail), [14, 15]. By this analyses, area of stray current activity on rails and metal objects can be detected. Stray current activity can be categorized considering different values of potential as it is shown in Table 1.

Table 1 Stray current activity considering different values of potential change, [19]

Potential shift [ΔV]	Stray current influence category and remedy
‹ 25	Negligible
– 75	Low – no further evaluation recommended
– 150	Moderate – further evaluation recommended based on the structure and protection levels
› 150	High – further evaluation recommended

According to the norm EN 50122-2:2011 [20] continuous monitoring of electrical potential at DC traction system is necessary, [20]. To make adequate calculation of average potential, period of 24 hour is recommended. If it is noticed bigger change in average rail potential, rail to earth resistance might become weaker, which mean that insulation material of the rail has loosen his performance. At cases like this the assumption is that current started to leak at the area of changed potential, [20]. This method does not affect the train traffic and the rail potential is registered at dedicated locations along the line, like in substations or passenger stations, [20]. Passenger stations are dedicated location because at these places vehicle is accelerating and decelerating. During the acceleration the amount of stray current is increasing (Figure 3), [21]. This negative effect can be reduced by placing substation near points of maximum acceleration, [22].

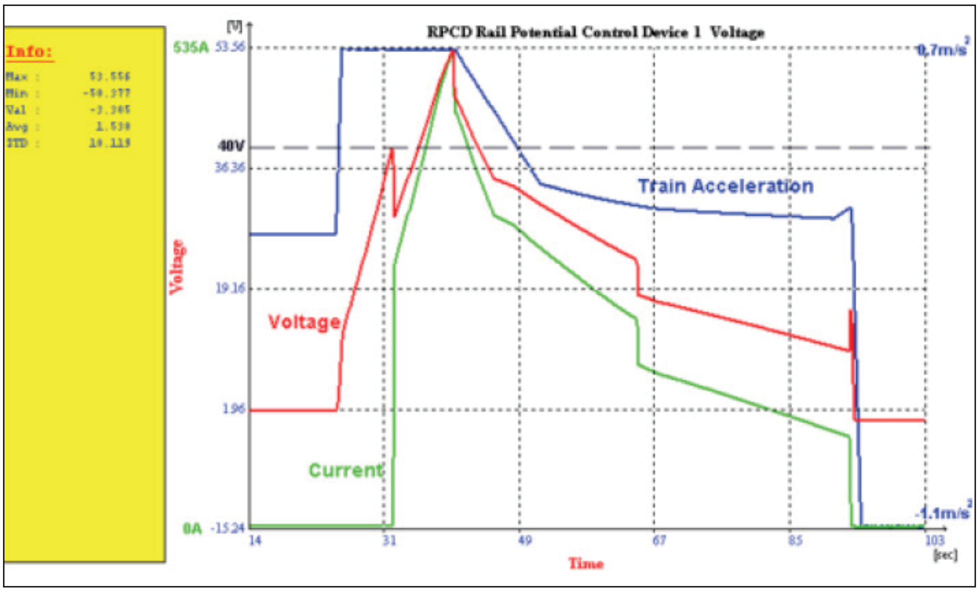

Figure 3 Change in voltage and current during the acceleration period of the vehicle, [21]

3 Stray current reduction at the source

DC transit system operators recognized stray current corrosion problem and they suggested different types of measures for reducing stray current leakage at the source. Today the most often measures can be sorted at two groups, [22]:

- Increasing rail to earth resistance,
- Decreasing electrical resistance of the negative return (rail).

Since stray current jeopardize buried communal infrastructure in the vicinity of the rails, measures for reducing stray current at the source often aren't enough so metal pipelines have to be protected from stray current corrosion by covering, coating or today mostly used method – cathodic protection, [1, 19].

3.1 Decreasing electrical resistance of the negative return (rail)

By welding rails are continuously connected. In this way less resistance of negative return (rail) is achieved, [24]. To split the return current proportional to both parallel rails, they have to be mutually connected at least every 100 meters, [1].
Electrical resistance of the negative return is decreasing by using rails with a bigger cross section, [25]. In this system rails represent electrical conductor and resistance of conductor becomes smaller with the bigger cross section and vice versa, [25]. Resistance also depends on a length of the conductor. Shorter conductors are resulting with the smaller electrical resistance and because that it is recommended to reduce distance between electrical substations. But with less distance between two substations the construction costs become bigger. This measure can be installed only at the time when new traction system is under construction, [24].

3.2 Railway structure

Conductance per unit length of the rail is the most important parameter in defining stray current leaking. If almost perfect insulation of rail is ensured and electrical conductivity of rail to the ground is reduced, amount of stray current will be at the minimum, [26]. Rail to ground resistance depends on the type of railway structure, quality of the railway fastening insulation material, elastic pads under the rails (if the rail is placed on the sleepers) and electrical resistance of the ground, [14, 22]. In the classic railway structure (especially with the wooden sleepers and broken stone as ballast material) rail to ground resistance can be up to 100 times bigger compared with the embedded railway structure, which is the most often construction in urban rails, [1]. The most effective way for reducing stray current leakage is improving electrical resistance at the metal/electrolyte interface.
Adequate insulation of the rails can be ensure by installing rail boot on the whole length of the structure or by ensuring adequate insulation of fastening system, [27]. Among the operators rail rubber boots are used as one of the most often method for reducing stray current (figure 4). This solution, except stray current, also reduces vibration of the rails, [28]. But by total insulation of the rails from the soil high voltage at the rail/soil interface is creating, which is representing huge danger for the users of railway infrastructure, [23].

Figure 4 Rail boot placed on whole length of the rails, [24]

During the exploitation time and under the influence of traffic load, weather condition and inadequate drainage in the railway structure, degradation of rail boot is occurring, [28]. According to the experience of DC transit system operators, measures that have to be implemented to extend lifetime of rail boot at classic railway structures are, [28]:

- Maintain dray and clean tracks (ensure adequate drainage of the railway gauge),
- Regular visual inspection of the track,
- Regular checking for the voids or loose connections at the boot sleeves (on the places where boot overlaps).

When the new railway tracks is building it is necessary to conduct the analysis of danger from corrosion in the cooperation with the corrosion engineers responsible for underground structures. Analyses like this should contain information about electrical resistance of the ground, values of stray current at the underground structures, stray current source, duration and magnitude of stray current and existing methods of stray current protection that are used in underground structures, [27].

4 Conclusion

Stray current corrosion issue is recognized among the world. DC transit system operators are investing lot of money for implementing different types of monitoring system in order to detect spots of stray current leakage. Stray current corrosion is a specific type of electrochemical corrosion that jeopardize railway infrastructure and buried metal object in the vicinity of railway. Although different measures for reducing stray current at the source are used today, adequate solution for completely stopping the leakage of current at the source still doesn't exist. Because of that, except reducing stray current at the source, it is also necessary to protect buried metal object. Due to the interdisciplinary of this area by measuring stray current at the buried pipelines, it is possible to detect place of entering current at the pipelines which is corresponding to the place of leaving current from the rails and vice versa. On that way operators can discovered potentially endangered places (anodic zones) on their infrastructure and implement adequate protection to reduce harmful consequence of stray current corrosion.

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