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Investigation on corrosion rate and a novel corrosion criterion for gas pipelines affected by dynamic stray current

Saeed Reza Allahkaram [a,*], Michael Isakhani-Zakaria [a], Mohammad Derakhshani [a], Masoud Samadian [b], Hojjat Sharifi-Rasaey [b], Ashkan Razmjoo [b]

[a] School of Metallurgy and Materials Engineering, College of Engineering, University of Tehran, Tehran, Iran
[b] Research & Technology Affairs, Tehran Province Gas Company, Tehran, Iran

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ABSTRACT

Influence zone of the dynamic stray current from subway was determined on parallel and crossed gas pipelines via synchronized potential measurements at different transverse distances from railway right of way. Results showed that the interference magnitudes decrease substantially with increasing the distance. Twenty-four hour monitoring of pipe to soil potential, lead to a new corrosion criterion for the affected pipelines depending on the type of coating used. A procedure based upon potential measurements has been developed for field investigations. Calculations of corrosion rate via Faraday law and weight loss measurements using corrosion coupons were also carried out.

1. Introduction

Stray currents are those currents which deviate from their intended paths. Depending on their sources, they can be either direct or alternating currents (Dc or Ac). Due to their low electrical resistance, underground metallic structures, such as coated pipelines and reinforced concrete, tend to pick up these currents, carry them as an alternative route and subsequently discharge them into the earth, back to their original source. Current pick-up areas of the buried structure will be electrochemically protected, while the current discharge areas can be subjected to corrosion. The significance of the corrosion phenomena depends on the magnitude and duration of the stray current (Bertolini et al., 2007; Solgaard et al., 2013; Nikolakakos, 1998).

The pipeline transportation of oil, gas and petroleum products is of great importance for a country's economy and its protection from corrosion is vital. Not to mention the fact that in case of failure, it can lead to pollution of the environment and subsequently create hazards to human life. The evaluation of corrosion hazard in a buried metallic structure is frequently determined on the basis of its potential that is measured with respect to a reference electrode. This measured potential, has a constant value, when no stray currents are present, which is called stationary potential. In the case of stray current flow, the potential of the structure begins to change. Thus, when the field measured potentials vary with time, the presence of dynamic stray currents is deduced. Potential measurements are carried out using a voltmeter with high internal resistance and a reference electrode (e.g. copper/copper sulfate electrode (CSE)) placed on the ground on the top of the buried structure (Zakowski and Darowicki, 2000; Glazov and Shamshetdinov, 2002; Freiman, 2004; Zakowski and Sokolski, 1999).

Electric traction systems are the biggest and best known sources of stray current due to the longitudinal resistance of the rails as current return circuit and the insufficient or damaged insulation between the rails and the ground. Dynamic nature of the stray current generated by Dc traction systems is due to continuous track to earth potential changes in the railway. These fluctuations are affected by transit vehicle acceleration and deceleration, and the number and location of vehicles on the system, among other influencing factors. Measuring structure to electrolyte potential fluctuations and the deviations from normal potential are two principal ways to identify stray current interference and estimate its magnitude. This may be achieved by recording the potential

* Corresponding author. P.O. Box 11155-4563, Tehran, Iran.
E-mail address: akaram@ut.ac.ir (S.R. Allahkaram).

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measurements using a digital data logger. Monitoring may be carried out over 24 h period in order to record the maximum and the minimum interference (Kerimov et al., 2006a; Kerimov et al., 2006b; Kerimov et al., 2006c; Zakowski and Sokólski, 1999).

In this research, effects of stray currents generated by Dc traction system (subway) on cathodically protected gas pipelines in the city of Tehran has been investigated. The influence zone of the subway stray current on pipelines with parallel and crossed alignment with respect to the railway right of way was determined via field investigations using one hour potential measurements. Twenty-four hour potential monitoring was also carried out in different locations which lead to a new criterion for dynamic stray current interference and related corrosion possibility. Corrosion rate of the stray current affected pipeline was estimated via coupon current monitoring and was compared to weight loss measurements.

2. Materials and methods

Tehran subway runs by means of a 750 VDc power supply and consists of three underground main lines together with some above ground lines and many stations. The above ground stations are usually located at the end of each trip line. Gas distribution networks in the city lie at a depth of 1.2 m underground and are protected by both coating and impressed current cathodic protection via several deep well ground beds.

In order to identify subway dynamic stray current effects on cathodically protected gas pipelines, field measurements of pipe to soil potential were carried out at selected test points (TPs) using a high internal resistance voltmeter (RM-16 Ziegler), a copper/copper sulphate portable reference electrode (RE-5C MCM) and a digital data-logger (RM-232 Ziegler). The device was capable of recording data in a range of 0.05–5 s time intervals. The field data were subsequently transferred to a computer and potential vs. time graphs were plotted using a suitable software.

The corrosion coupons were made from API X65 steel sheets (similar to pipeline composition) cut in 5*5 cm^2 with 3 mm thickness, which were coated with coal tar coating with exposed steel surface area of 1 cm^2. Shielded copper wires were used to electrically bond the coupons to the pipeline (at a TP). The coupons were buried near the pipeline at a similar depth and the wire leads were collected in a bond box for potential and current monitoring.

After removal of coupons and cleaning of corrosion products, weight loss direct measurements and calculation using coupon current density (via Faraday law) followed by corrosion rate determination were carried out according to the ASTM standards (Preparing et al., 1999; Calculation of corrosion, 1999).

3. Result and discussion

3.1. Transverse potential measurements

In the first step, in order to identify the stray current interference and specify its influence zone, one hour potential measurements at various transverse distances from railway were carried out in the vicinity of two different stations (A and B). These stations were chosen due to their difference in pipeline alignment in the neighbourhood. As shown in Fig. 1, in the station A, the pipelines lie in parallel position with respect to the railway right of way, while in station B, the pipeline crosses the railway. Moreover, station A lies at about 50 m underground (deepest station available), whereas station B is located above ground.

Three one hour potential measurements in each of these two stations were carried out simultaneously in three different transverse distances from the railway i.e. less than 10, 500 and 1500 m. Thus, in station A, the acquired data corresponds to three different but parallel pipelines, while in station B three measurements have been carried out along the same pipeline crossing the railway (Fig. 1). The data was recorded with one second interval for one hour. For better comparison, a period of five minutes from each three measurements in both stations is shown in Fig. 2 and Fig. 3. It can be seen that, the potential fluctuation patterns are similar for all three potential measurements at each station and no time lag is observed. It only keeps damping by moving away from the railway in which case the data collected with respect to the station A is more pronounced than that of the Station B (Fig. 2). In station A, soil is the only means of resistance to the flow of dynamic stray current as the distance increases from the station. But in station B, the only resistance is the longitudinal resistance of the pipeline itself and thus, there is no significant reduction in the intensity of transmitting signal (Fig. 3).

It is a well-known fact that direct measurement of the dynamic stray current is impractical. Therefore, the potential of the influenced structure against earth (*IR* drop component included) and its deviation from steady state potential (in the absence of stray current) is normally taken for assessment. Hence, in this research, the pipeline potential fluctuations influenced by the subway dynamic stray current, are measured as comparable parameters of stray current interference. This was in accordance with other researcher's evaluations (Zakowski and Darowicki, 2000; ZhiGuang et al., 2013).

Extracted parameters from Figs. 2 and 3 are shown in Tables 1 and 2. The maximum and the minimum values of the potentials listed in these tables are the average values of the maximum and minimum 10% of the acquired data for each point in order to reduce errors caused by random data.

Potential fluctuation magnitude (PFM), which is the difference between maximum and minimum potential values, drops from 4 V near the station A to as little as less than 100 mV in the distance of 1500 m away from the railway. In station B, this value remains at around 200 mV and does not show any significant drop by moving away from the railway. It can be deduced that the distance between pipeline and the source of DC stray current (e.g. in the case of station A is about 50 m and in the case of station B is about 2 m) does not seem to be directly proportional to the resulting interference (the PFM). Other parameters such as soil resistivity and the magnitude of interference (which is influenced by the positions of the dynamic stray current source, CP rectifier station, anode well and the pipeline itself) may be involved.

Apart from the PFM, the frequency of the potential fluctuations may also affect the corrosion process. it is a well-known fact that the corrosion damage by AC is less than that of DC (when considering AC as a fluctuating DC with high frequencies), with the resultant corrosion usually being greater at lower frequencies and being less at higher frequencies. It can be concluded that if the frequency of fluctuating direct stray current is high enough in a way that interferes with the formation of electrical double layer on the anode in the electrochemical process of dissolution, then the corrosion process will be hindered (Winston Revie and Uhlig, 2008).

However, since the frequency was almost constant in all potential measurements (changing randomly between 1 and 3 Hz) due to being directly influenced by the frequency of the fluctuations of the contact voltage of the rail (as the source of the stray current), It was not possible to study the effect of frequency.

3.2. Map analysis

In order to specify test point locations for potential monitoring, the subway and the gas pipeline network maps were superimposed