Methods of Evaluation of the Corrosion Hazard Caused by Stray Currents to Metal Structures Containing Aggressive Media

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Abstract

Typical methods have been characterized of determination of the corrosion hazard caused by stray currents to metal structures transporting or storing aggressive media (e.g. fuel pipelines, tanks). Monitoring of the hazard allows determination of its extent, facilitates choice of the most appropriate anticorrosion protection method individually for each structure, and also enables evaluation of the effectiveness of a functioning protective installation. This paper assesses the practicability of the above-mentioned methods. Application of methods leading to erroneous conclusions regarding the corrosion hazard of electrolytic corrosion in relation to real electrode processes occurring on the metallic surface of the structure can lead to dangerous consequences. The effect of corrosion processes is the corrosive perforation of metal leading to leakage to the ground of aggressive media, contaminating the natural environment. Seeking new unequivocal methods regarding electrolytic corrosion processes proceeding on structures is a fundamental issue.

Keywords: corrosion, stray currents, leakage, ecology

Introduction

The problem of electrolytic corrosion caused by stray currents is the subject of an increasing number of scientific publications. It is one of the more important present-day corrosion problems. Thus, it also is an economic and social problem. The fact that stray currents can indirectly cause a significant ecological hazard is being more fully appreciated. The authors of this paper discussed the problem in this journal [1] and in papers [2] and [3]. We have indicated that electrolytic corrosion of metal underground structures can lead to leakage of transported or stored aggressive media (oil, liquid fuels, hot water, gas). Pollution of the natural environment and hazards to human life are consequences of, for example, gas explosions. Also, sources of stray currents have been characterized [1-3], corrosion processes described occurring on metal structures during flow of stray currents, and anticorrosion protection methods presented of structures endangered by the harmful interaction of stray currents.

Metallic underground structures can be protected from corrosion by electrochemical protection methods. The choice of an appropriate protection method (cathodic protection, sacrificial anode protection, electric drainage) is made on the basis of results of specific field measurements. Also, the effectiveness of protective installations is evaluated on the basis of measurement results. Appropriate protection from corrosion of industrial structures leads to avoidance of corrosion break-downs, to limiting pollution of the natural environment by hazardous media leaking out of structures.

The aim of this work is to evaluate practical methods used for determination of the extent of the corrosion hazards caused by stray currents.

Corrosion Effect of Interaction of Stray Currents

A number of factors affect the kinetics of corrosion processes of external surfaces of metallic structures containing aggressive media. One of them is current interfernce, e.g. interaction of stray currents.

In municipal and industrial agglomerations stray currents are random, dynamic and bipolar in character. This indicates not only that the current and flow route change, but also the direction of flow through the metal/electrolyte phase boundary. Flow direction depends on the instantaneous parameters of stray current sources, including the actual momentary load of the electric traction. Therefore, the effect of stray current interaction (metal mass loss due to corrosion) depends on many factors. Due to the properties of stray currents, evaluation of the electrolytic corrosion hazard to a structure is a complex problem.

An electrolytic corrosion process occurs on the external metal surface during outflow of stray currents from a structures to the surrounding ground. The process is dissolution of the metal caused by flow of electric current through the metal/electrolyte phase interface. A measurable effect of this process is a change of the structure potential in the positive direction (anodic polarization). The current flows between the metal and electrolyte in places of defects of the structure's external insulation. In these places perforation of the wall can take place very quickly, especially at high current densities (small insulation damage area). Such types of corrosion damages in the form of pits or holes are typical for electrolytic corrosion. Descriptions of such breakdowns can be found the world literature (e.g. [4, 5]).

In periods when stray currents flow from the ground to the structure, corrosion processes are hampered. The structure is cathodically polarized and its potential changes in the negative direction.

Detection of Presence of Stray Currents

The potential of a structure measured versus the reference electrode has a constant value when no stray currents are present. This is called stationary potential. The potential of a structure dramatically changes in regions of occurrence of stray currents as the result of induced polarization, which is random in character. Changes can take place in the positive, as well as the negative direction in relation to the stationary potential. Thus, on the basis of a field potential measurement of a structure and variations of the measured signal one can deduce the presence of stray currents. The potential measurement can be performed with a voltage meter of high internal resistance (minimum 100 kΩ/V), as illustrated in Fig. 1. One of the outputs of the meter is connected to the structure with a cable (e.g., in measurement-control points or with fittings accessible in inspection chambers). The second input of the meter is connected to the reference electrode, which is placed on the surface of the ground as near the structure as possible. The copper sulphate reference electrode is used most frequently in field conditions. Nowadays microprocessor digital voltmeters and digital recorders are commonly used. One may assume that if during a period of several minutes the difference between the minimum and maximum potential values exceeds 50 mV, then the electrolytic corrosion hazard to the structure should be investigated in the place of measurement. The greater the potential range, the greater intensity of stray currents in the measurement region and a greater probability of their harmful interaction. One may to some approximation assume that if the mean value of a steel structure potential is more positive than -400 mV versus the copper sulphate electrode, then a high electrolytic corrosion hazard exists; if the value is more negative than -700 mV, then no hazard exists. However, it is not a rule, therefore the above criteria cannot be applied uncritically.

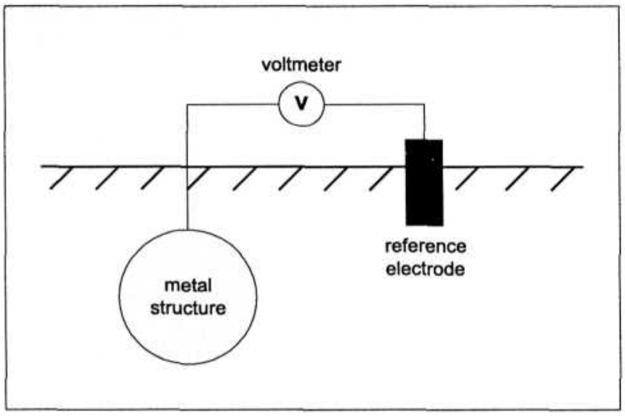

Fig. 1. Potential measurement of structures.

Stray currents cause the electric field in the ground connected with their flow through the electrolytic environment to change in time and in space. Changes of this field are random in character. Therefore, the presence of stray currents can be detected by investigating changes of the electric field vector in the ground. Usually such investigations are performed by measuring voltage drops with a two-channel recorder in the ground in two X-Y directions perpendicular to each other, between identical reference electrodes at a distance of approximately 30 m from each other (Fig. 2). A constant value of the electric field vector in the ground points to lack of dynamic stray currents in the place of measurement. A dynamically changing measured value points to the occurrence of stray currents in the region. On the basis of the sign of the electric field vector one may determine the stray current flow direction in that area.

Dynamic changes of the structure potential or electric field vector in the ground only point to the presence of stray currents. It is difficult to draw conclusions as to the direction of the polarization: anodic, cathodic or alternating (periods of alternating anodic and cathodic polarization). The more so, it is impossible to draw conclusions on electrode processes occurring on the surface of the metal structure.

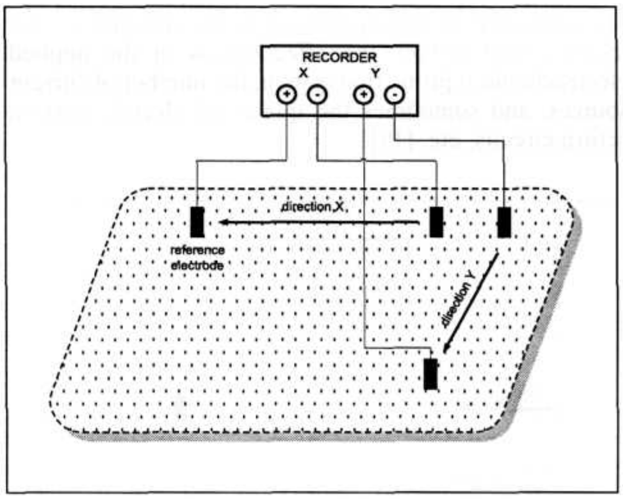

Fig. 2. Measurement of electric field distribution in the ground.

Determination of the Corrosion Hazard Caused by Stray Currents

Measurement results of the electric field vector in the ground are sometimes used for determination of the extent of the stray current corrosion hazard [6]. However, valuation of their intensity is practically impossible by this method. One may only compare absolute values of the measured signal with those from other regions and on this basis indicate places of occurrence of greater stray currents. This method does not allow drawing of conclusions on the effectiveness of functioning of anticorrosion electrochemical protection installations.

In order to determine if a given underground structure is in an anodic or cathodic interaction zone of stray currents flowing out of electric tractions (tram, rail), one can investigate the electric field in the ground caused by the presence of the traction. To accomplish this, potential measurements are carried out of rails in relation to the so called distant ground. The measurement is based on determination of the potential difference between a fixed rail point and a reference electrode placed on the surface of the ground at some distance perpendicular to the railway line. The principle of rail potential measurement is illustrated in Fig. 3.

Investigation of rail potentials allows determination of their anodic and cathodic zones. A negative rail potential (the cathodic zone) appears in places of inflow of currents from the ground to electric traction rails. In the cathodic zone of rails a hazard exists to neighbouring underground structures caused by interaction of stray currents, as encountered conditions facilitate outflow of these currents from the structure to the ground (anodic zone on underground structures). A positive rail potential indicates occurrence of an anodic zone and, simultaneously, a cathodic zone of metal underground structures. In such a case no hazard exists to the latter caused by electrolytic corrosion. Comparison of instantaneous rail potential values at various distances (e.g., several or tens of meters from the rail) allows determination of the "steepness" of the voltage cone in the ground. The greater the difference in potential values, the greater the value of the electric field in the ground, and thus an expected greater intensity of stray currents.

Analysis of the potential distribution of rails only determines the probability of occurrence of electrolytic corrosion of metal structures, as it describes only the external factor. No conclusions can be drawn as to the real flow of stray currents through the structure in the region of field measurements, as well as on the occurring electrolytic corrosion processes. In an extreme case the following situation can take place: the potential distribution of rails points to occurrence of an anodic zone on the underground structure (very high electrolytic corrosion hazard), whilst the structure has an excellent insulation in this region and the currents outflow from the structure in distant regions, where the corrosion process takes place.

Standards and regulations propose adopting the value of the structure potential and the magnitude of its variations as an electrolytic corrosion hazard criterion [7, 8]. Conclusions concerning the hazard of corrosion caused by stray currents should be drawn on the basis of calculated mean values of the potential shift in the positive . and negative direction in relation to the stationary potential value. It is recommended to measure the stationary potential in the period of expected lack of stray currents (e.g., at night) or it is suggested to adopt a value of 500 ,mV versus the copper sulphate electrode. This method allows determination of only an approximate value of the electrolytic corrosion hazard, not only due to use of an approximate value of the stationary potential, but mainly due to burdening of measurement results with the IR component (ohmic voltage drop mainly on the resistance between the structure and the reference electrode).

Measurement techniques used in cathodic protection systems when the electric field in the ground is static in character are unreliable in dynamic stray current interaction zones [9]. Very fast potential changes produced by a current flowing through the metal/electrolyte phase interface in a random direction and a random polarization value of the structure are the cause of unreliability. Fleig [10] indicates that for the same reason intensive measurements are not useful in the region of interaction of stray

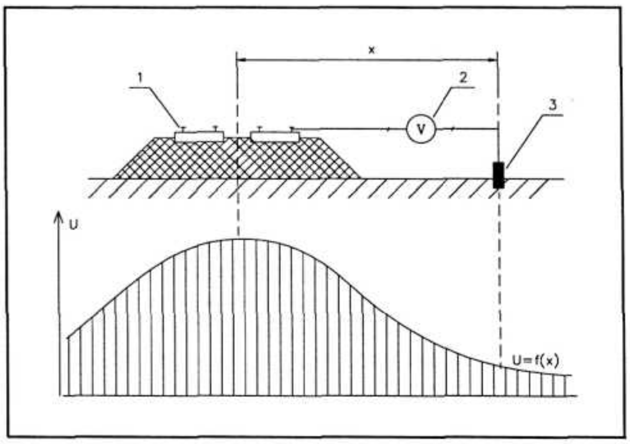

Fig. 3. Potential measurement of electric traction rails:
1 - rail, 2 - voltmeter, 3 - reference electrode.

currents (potential measurements along the pipeline route every several meters or less, carried out to detect insulation defects). Pourbaix et al. [11] bury next to the structure a probe containing a reference electrode and a coupon galvanically connected to the structure, simulating a defect of its insulation. After finishing exposure and removal of probes the corrosion hazard is estimated on the basis of gravimetric measurements. Drawbacks of the method are high costs and the possibility of obtaining results only after a long time. Limitations of the coupon exposure method lead to its application rather for evaluation of effectiveness of protective installations [12], than the hazard caused by stray currents.

Investigation methods outlined in brief below are those most frequently applied in regions of interaction of dynamic stray currents. Martin and Brinsmead [13] measure for two minutes the underground structure potential and the current flowing through the coupon connected to the structure. By using the linear regression method they determine the potential corresponding to the zero value of the current. This potential is assumed to be the structure polarization potential. Park, Cho et al. [14] propose performing of measurements of independent structure potentials and electric traction rail potentials. They determine the activity of stray currents by reporting mean values of these potentials and their standard deviations. These scientists stress that if stray currents interact with the structure, then potentials of the structure and rails change symmetrically in relation to each other. However, from these data one cannot always draw conclusions regarding the mean direction of polarization caused by stray currents. Thus, valuation of the electrolytic corrosion hazard is practically impossible. The cited authors determine the places of inflow and outflow of stray currents from the pipeline on the basis of measurement of the direction of current flowing along the pipeline. This method is of relatively little use in regions of occurrence of bipolar stray currents (changing the flow direction through the metal/electrolyte phase interface). Bazzoni and Lazzari apply the "side gradient technique" [15, 16]. They extrapolate the functional dependence after a several minute measurement of the structure potential and the gradient of the electric field in the ground in a direction perpendicular to the structure. They use two portable electrodes, of which one is placed above the pipeline, the second at such a distance so that the measured voltage drop is equal to approximately 20-30 mV. They call the potential value obtained by extrapolation the real potential of the structure devoid of the IR component. This measurement technique is used for underground pipelines, as well as reinforced concrete structures.

In Poland the correlation method is used for investigating stray currents. It was been elaborated many years ago at the Technical University of Gdansk [17, 18]. The method is based on simultaneous measurement for a period of 20-30 minutes of two quantities connected with the presence of stray currents. The structure potential E and voltage U in relation to the current source are measured (Fig. 4). Next, the mutual correlation spectrum$E=f(U)$ is analyzed by computer techniques. From the shape of the spectrum, its slope, concentration areas, discontinuities, perturbations, bends, shifts - conclusions are drawn as to the character of interaction of stray currents in the measurement region, the effectiveness of the applied electrochemical protection system, the number of current sources, and sometimes the quality of electric traction return circuits, etc. [19].

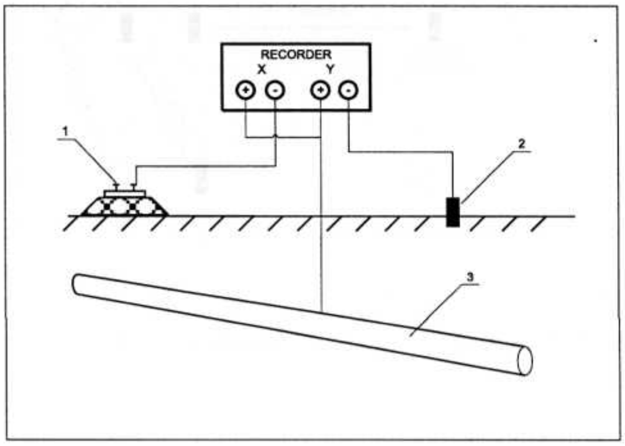

Fig. 4. Method of connection of a recorder to the rail (1), reference electrode (2) and pipeline (3) for measurements by the correlation method.

In the correlation method the electrolytic corrosion rate is connected with the asymmetry of structure potential changes versus the stationary potential. This is taken into account in the so called potential asymmetry coefficient, which has been assumed to be the measure of the hazard caused by harmful interaction of stray currents. It is assumed that when the value of the asymmetry coefficient is greater than 30%, then application of electrochemical protection from stray currents is essential (electric drainage, cathodic protection). The correlation method is best applied in practice for determination of interaction of stray currents flowing out of electric tractions. The probability of electrolytic corrosion determined by this method is correct especially for pipelines with bad insulation, intersecting with traction rails. Observations in such places point to this (including measurements of stray currents drained from pipelines to rails).

In the above method many doubts are raised by the assumed measure of the electrolytic corrosion hazard. The magnitude of the asymmetry coefficient does not always have to be in compliance with intensity of electrode processes on the metal surface. Also, during anodic polarization periods not only ionisation of metals occurs, but also a number of other electrode reactions dependent on the chemical composition of the environment (e.g., oxygen, chlorine evolution) and its physical parameters (temperature, conductivity). Additionally, phenomena take place dependent on the frequency and density of current, capacitance of the double layer, charge transfer resistance. During flow of current in the anodic direction metal dissolution takes place in parallel with charging of the double layer and is smaller, the smaller the fraction of faradaic current in relation to the capacitive current. Due to the above phenomena, on the basis of the correlation method one not always can correctly evaluate the real hazard caused by harmful stray current interaction.

Conclusions

Corrosive stray current interaction on metal underground structures containing aggressive media (e.g., fuel pipelines, tanks) can lead to leakage and pollution of the natural environment. Effectively working anticorrosion protection installations minimize this danger. Correct choice of protection methods requires accurate determination of the magnitude and type of corrosion hazards.

The presence of stray currents can be easily detected. After a short training this operation can be performed by basic technical personnel with simple measurement tools. Specialists are required later for the correct evaluation of the electrolytic corrosion hazard, and next for the evaluation of the effectiveness of protective installations.

Investigation methods described in the world of scientific literature, used for evaluation of the corrosion hazard in stray current interaction conditions, are not based on unequivocal and precise hazard criteria. No progress in the description of interaction of stray currents has been observed for many years.

Seeking out new investigative methods is necessary. The authors of this work see possibilities of investigation of potentials in the time-frequency domain with the use of most recent mathematical tools. In this way obtaining data is expected on electrode processes taking place on the surface of a metal structure endangered by the harmful interaction of stray currents.

One of the measurable effects of elaboration and propagation of electrolytic corrosion hazard evaluation methods will be a decrease in the number of breakdowns leading to pollution of the environment by media leaking out of metal structures.

Acknowledgements

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