Short communication

Visualising dynamic passivation and localised corrosion processes occurring on buried steel surfaces under the effect of anodic transients

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A B S T R A C T

A new method of visualising dynamically changing electrode processes has been demonstrated by mapping localised corrosion processes occurring on buried steel surfaces under the effect of anodic transients. Dynamically shifting external electrical interferences such as anodic transients are known to affect the efficiency of cathodic protection (CP) of underground pipelines; however unfortunately conventional techniques including electrochemical methods have difficulties in measuring such effects. In this paper we report that the wire beam electrode has necessary temporal and spatial resolutions required for measuring and visualising the dynamic effects of anodic transients on CP, passivation and localised corrosion processes occurring on buried steel surfaces. For the first time a critical anodic transient duration has been observed and explained as the incubation period for the breakdown of passivity and the initiation of localised corrosion.

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1. Introduction

Buried steel structures such as underground pipelines are considered to be effectively protected by cathodic protection (CP) when a stable CP potential of −850 mV vs. $Cu/CuSO_4$ reference electrode (CSE) is applied on it [1–3]. In practice, however, significant pipeline potential excursions from this 'safe' CP potential could occur due to various forms of external electrical interferences, often referred to as stray currents [4–7]. A common form of external electrical interference is anodic transient that causes the steel pipeline potential to shift rapidly towards the anodic direction. Anodic transients are believed to significantly reduce CP efficiency [5]; however currently there is little understanding of the effect of either their magnitude or duration on the likelihood of steel depassivation and thus a possible catastrophic pipeline failure [4]. Therefore, over the past several decades many attempts have been made to develop 'rules' for quantifying the effect of anodic transients on the corrosion of cathodically protected buried steel pipelines. Unfortunately these 'rules' remain empirical because they are based on field inspection data that are generally accumulated results from various complex and long term factors affecting pipeline corrosion [5–7]. For instance Peabody [6] described a 'rule' that an anodic transient of 1 h duration would lead to a 27% increase in buried pipeline corrosion risk whilst an anodic transient of 1 day's duration would increase the 'chance' of corrosion by 50%. Although this 'rule' clearly points out the importance of the duration of anodic transients, it does not give any clear justification or fundamental understanding for the choice of these durations. A better understanding of the influence of anodic transients on corrosion for CP protected structures would be of significance for both pipelines and other buried infrastructure. The ability to directly probe corrosion currents on cathodically protected metal structures under different conditions and in the presence of stray currents would allow such an understanding. However, at present empirical field data remains the only means of quantifying the effects of dynamic anodic transients on buried pipeline corrosion [4,7].

Whereas conventional corrosion testing methods such as weight-loss coupons and electrochemical polarisation measurements provide average corrosion rates, an electrochemically integrated multi-electrode array, often referred to as a wire beam electrode (WBE), is capable of detecting time dependent localised corrosion. In this work we take advantage of the high temporal and spatial resolution of the WBE, which has previously been demonstrated to be capable of measuring corrosion under stable CP conditions [9], to probe dynamic localised electrode processes evolving and propagating on buried steel surfaces under the effect of anodic transients. Using the WBE, we show for the first time that, under dynamically changing CP conditions, we can measure the evolution of localised corrosion processes and correlate this to the nature of the environment, as well as the duration and amplitude of the transient. This technique would enable an understanding of the changing local passivity conditions on buried steel structures.

2. Experimental

Fig. 1(a) presents the experimental configuration using a WBE sensor to enable the in situ monitoring and visualisation of electrochemical

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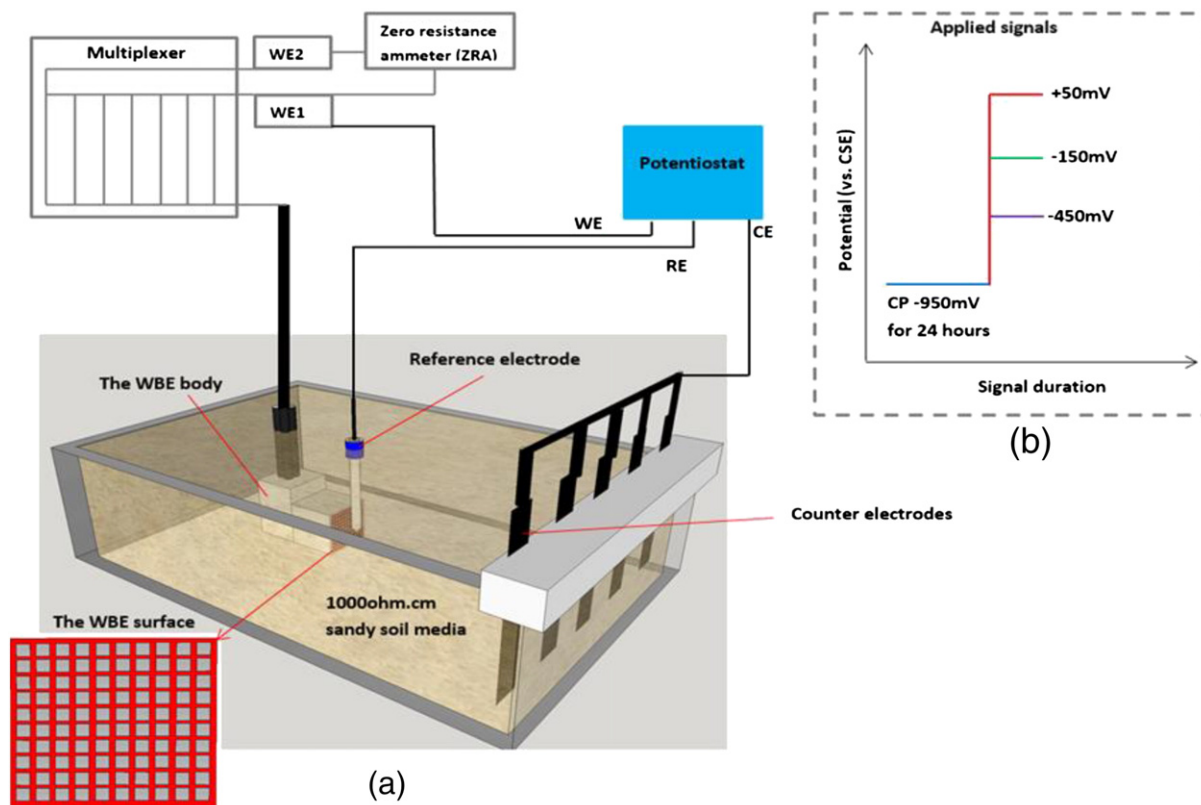
Fig. 1. (a) The experimental configuration using a WBE probe to facilitate the in-situ monitoring and visualisation of electrochemical processes occurring on buried steel surfaces under CP and anodic transient conditions in a soil cell; (b) typical applied CP and anodic transient signals. Note: the potential is shown in the Cu/CuSO₄ reference electrode (CSE) scale. The potential of the Cu/CuSO₄ electrode is $+0.314$ V with respect to the standard hydrogen electrode (SHE).

processes occurring on buried steel surfaces under CP and anodic transient conditions. The WBE probe used in this work consists of 100 closely packed but isolated electrodes made of square shaped (1.9 mm × 1.9 mm) type 1020 carbon steel (UNS no. G10350) embedded in epoxy resin. The gaps between neighbouring electrodes were kept small (0.10 ± 0.05 mm). After grinding using SiC grit paper, the probe was installed in a specifically designed sandy soil box cell [7] that facilitates the effective simulation and control of CP testing conditions. Washed fine sand with typical resistivity of 1000 Ω cm was used in the sand box cell, and the resistivity was adjusted using a 3% NaCl solution. The sand box cell was sealed to prevent evaporation. The electrode array connections were managed by an automatic switcher programmed to connect the selected electrode to WE2 and the remaining 99 electrodes to WE1 (switching once every second). In this way, current distributions over the whole electrode array are measured by completing a scan every 100 s. A potentiostat (Bio-Logic Science Instrument) was used to apply CP and anodic transient signals on the WBE probe surface under potentiostatic control. Fig. 1(b) illustrates three typical anodic 'step change' signals that have been used to simulate the anodic potential shift in what is commonly referred to as an anodic transient signal. A Ag/AgCl (Sat. KCl) electrode was used as a reference electrode and a Ti-mesh set was used as the counter electrode by combining five 15 cm by 1.5 cm titanium-mesh strips. Electrode potential has been converted CSE scale because CSE is the most commonly used reference electrode in the CP industry and its standards. The currents obtained by ZRA were used to construct current density distribution maps and to calculate the local corrosion rates based on Faraday's law. The same experimental setup was also applied in separate aqueous experiments whilst the cell was filled with a 1000 Ω cm NaCl solution [7]. More details on the experimental and data analysis methods can be found elsewhere [7–9].

3. Results and discussion

Fig. 2 shows the typical current density recordings and WBE maps obtained using the WBE probe under the effects of anodic step changes of different amplitudes (500 mV, 800 mV and 1000 mV). The current densities were recorded from the coupled electrode array under the prior CP potential and three different anodic step change levels, whilst the currents shown in the maps are measured from each individual electrodes. All experiments were started by applying a CP potential of −950 mV vs. CSE on the WBE for a 24 h period in order to establish a stable CP condition on buried WBE surfaces. Under prior CP, as shown in the relevant WBE map in Fig. 2, only cathodic currents (in negative values) were detected over the WBE surface, indicating that the probe was under cathodic protection and no corrosion would be expected. Immediately after the anodic transient signals were superimposed on the CP potential, the steel potential was shifted from −950 mV vs. CSE to +50 mV vs. CSE, −150 mV vs. CSE and −450 mV vs. CSE upon application of either 1000 mV, 800 mV or 500 mV, respectively. As shown in Fig. 2, an initial anodic current peak accompanying this shift in potential can be observed in all cases. This is believed to be due to an anodic current spike charging the double layer capacitance over the electrode surface in addition to metal dissolution current occurring over the anodically polarised WBE surface at these anodic transient potentials. As shown in map (a) of Fig. 2, an area with high local anodic current is observable on the background of a smaller uniform anodic current, suggesting that local anodic dissolution was occurring (0.1 mm/y) on the WBE surface immediately after the anodic step change was applied. This local anodic current can be considered to be due to localised metal corrosion because the current charging double layer capacitance over the electrode surface should be distributed rather uniformly as the background current in map (a). After approximately 5 min, as shown