Measurement 82 (2016) 46–54

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Investigation of pitting corrosion monitoring using field signature method

Fangji Gan [a], Guiyun Tian [b], Zhengjun Wan [a,*], Junbi Liao [a], Wenqiang Li [a]

[a] *School of Manufacturing Science and Engineering, Sichuan University, Chengdu 610065, People's Republic of China*
[b] *School of Electrical, Electronic and Computer Engineering, Newcastle University, NE1 7RU, UK*

ARTICLE INFO

Article history:
Received 12 January 2015
Received in revised form 27 November 2015
Accepted 28 December 2015
Available online 2 January 2016

Keywords:
Field signature method
Pitting corrosion
Potential drop
Resistor network

ABSTRACT

The field signature method (FSM) is a nondestructive testing (NDT) method based on the potential drop (PD) technique and has been applied to online metal pipe corrosion monitoring for nearly three decades. The many advantages and benefits of the method have been reported in a number of studies, but few have reported on its limitations or shortcomings. However, the detection accuracy for pitting corrosion in FSM is very low. In this paper, the reasons for the low pitting corrosion detection accuracy of FSM were analyzed and it was found that different corrosion pits, which have different sizes, depths or positions, generally have differing influences on the potentials of nearby electrode pairs. Therefore, a new method using a subdivided resistor network to assess pitting corrosion is proposed and verified. When compared with the traditional method, the most important parameter, namely the pitting corrosion depth detection accuracy, can be significantly improved.

1. Introduction

Corrosion is the main cause of pipeline failure [1] and pitting corrosion [2–4], a form of corrosion that produces defects in a limited area but often to considerable depths, is particularly insidious and is more difficult to detect accurately when compared with localized corrosion or other types of corrosion. Various traditional non-destructive testing (NDT) methods have been implemented to measure pitting corrosion, including ultrasonic thickness measurement (UTM), acoustic emission (AE), and electrochemical noise measurement (ENM) methods. Each method, however, has its limitations. UTM is a relatively cheap method and can be deployed easily with good accuracy [5], but it usually requires calibration for each material and needs a coupling material between the measured surface and the probe. AE, which is an effective non-destructive technique, has been used for the detection of fatigue cracks in a variety of metal structures for decades, and it can detect incipient damage on the micron scale, including fatigue, corrosion/erosion, fretting wear and sliding friction [6,7]. However, commercial AE systems require other NDT methods to perform further examinations and provide quantitative results, because AE monitoring can only assess the current rate of damage accumulation, and not the level of previously accrued damage; therefore AE generally cannot assess the remaining service life of a component, i.e., how long that component will last [8]. ENM is an emerging technique that is currently being used in corrosion monitoring and is proving particularly useful for detection of localized corrosion processes [9,10]. ENM can provide an indication of the type of corrosion damage that is occurring, and is widely used to distinguish between general and localized corrosion. However, there are no established ENM test methods and no theoretical framework for quantitative interpretation of the data to date [11].

---

* Corresponding author.
E-mail address: 815425639@qq.com (Z. Wan).

http://dx.doi.org/10.1016/j.measurement.2015.12.040
0263-2241/

When compared with the traditional corrosion monitoring methods mentioned above, the field signature method (FSM) [12] offers operational advantages, including the fact that no measuring components are directly exposed to harsh environments such as high-temperature and high-pressure conditions [13]; the sensitivity and reliability are better than those of NDT techniques; and foreign objects cannot be introduced into the measured pipe [14]; also, there are no consumables, so the measurement system can remain in service for as long as the lifetime of the measured pipe; once FSM was installed, there is no need to destroy the protective layer of the measured pipe during the whole service life of FSM; it can work over a wide temperature range (−40 to 350 °C) [15]; it is a long term online monitoring NDT method. Therefore, FSM is a good choice for subsea pipeline, buried pipeline or pipeline in high temperature, high pressure or poisonous gas environment.

FSM was first presented in 1983 by Hongestad in a patent [16]. It is a non-intrusive monitoring technique based on the potential drop (PD) technique. The PD technique is a highly versatile method and has been widely applied in numerous areas. For instance, Spitas et al. assessed fatigue crack growth in real time, even at high temperatures [17], and measured both the length and the direction of cracks [18] based on a modified potential drop technique. The sensing electrodes and all other test equipment for FSM are placed outside the structure to be monitored [19]. Initially, FSM was implemented to monitor cracks in the welded areas in subsea pipelines, and it can now monitor both general and localized corrosion, erosion and cracks in ferritic and metal structures, piping systems and vessels [20].

In 1991, Strommen et al. proposed a model for a modified FSM [20–22] that added a reference plate to reduce the effects of changes in temperature and excitation current. They also proposed the field fingerprint coefficient (FC) concept and algorithm that helped the FSM become more widely used. However, because of the technical limitations at the time, the deficiencies in the theory of FSM were not resolved, and therefore pitting corrosion was calculated using an empirical formula that can cause a considerable error [23].

In 2008, Farrell and Daaland found that the flow of the current around the corrosion is not well distributed on the basis of simulations and this can result in reduced monitoring precision. Also, the randomness of the size, depth and position of this type of corrosion makes it very difficult to calculate the current distributions [24,25].

In 2009, Sposito and Cawley from Imperial College discovered that the changes in potential may not increase monotonically with the defect size, because the defect alters the current distributions. To overcome this problem, the electrode distribution was optimized and the PD mapping technique was presented for defect monitoring applications [26]. However, the optimal solution offered for probe spacing is not universal, and the method used to calculate the current distribution was not mentioned.

In 2011, Wan studied and defined the drag effect [27], which is caused by current redistribution due to corrosion, and proposed a method to eliminate the influence of the current redistribution by calculating the distributions of the currents. However, this paper only investigated the influence of localized corrosion on current redistribution, and did not propose a method to calculate pitting corrosion.

In 2014, Gan proposed a method to assess pitting corrosion by matching with a corrosion database established using finite element analysis software [28]. This method can greatly improve pitting corrosion detection accuracy in FSM. However, because pitting corrosion conditions are quite complex, millions of different types of pitting corrosion exist. Therefore, the database must contain millions of simulations to ensure correct matching. In addition, different corrosion databases must be established when using this method to assess different pipes with different diameters, wall thicknesses or measurement electrode distributions. Thus, this method is not very practical or convenient.

And in 2015, Gan proposed an improved formula for localized corrosion in FSM based on analysis of current redistribution caused by localized corrosion [29].

This paper proposes an analytical mathematical model to calculate pitting corrosion by investigating the influence of pitting corrosion on the current field redistribution in the measured structure.

2. FSM principles

The FSM is based on Ohm's law and allows non-intrusive metal loss measurements of pipes and vessels [23,30–32]. Multiple measurement electrodes are welded on the outer surface of the pipe or structure to be measured to form a measurement matrix. For effective compensation of the temperature fluctuations, background noise and current variations, a reference sample, which is located in a region close to the monitoring electrodes, is adopted [32], as shown in Fig. 1(a). The measured region between a pair of electrodes can be regarded as a cube, and this cube can be treated as a resistor, as shown in Fig. 1(b). The width (w) and the length (L) of the equivalent metal cube are constant when the measurement electrode matrix has been welded. Therefore, if a constant current is applied to the pipe to be measured, then changes in the potential of the electrode can only be caused by wall thickness (WT) loss due to corrosion, erosion or other defects, as shown in Eq. (1).

$$\begin{aligned} &\Delta E = RI \\ &R \propto \frac{L}{T \cdot W} \\ &\Delta E \propto \frac{1}{T} \quad (W, L = cons) \end{aligned} \tag{1}$$

The corrosion condition in a measured region formed by a pair of electrodes is assessed by the FC, which is defined as [13,27,28,33]:

$$FC_i = \left(\frac{\frac{V_i(t_x)}{V_i(t_0)}}{\frac{V_{ref}(t_x)}{V_{ref}(t_0)}} - 1 \right) \times 1000 \tag{2}$$

where $V_i(t_0)$ and $V_i(t_x)$ are the voltage values of the measured electrode pair i at times t_0 and t_x, respectively.